Fawn survival, cause-specific mortality, and bed-site selection of white-tailed deer and mule deer in Western Kansas

by

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Abstract

Mule deer (*Odocoileus hemionus*) and white-tailed deer (*O. virginianus*) are common sympatric deer species in the Great Plains and western United States that have exhibited divergent population trends temporally and spatially. Mule deer populations are declining and contracting to the west while white-tailed deer populations are expanding. Species-specific differences in fawn recruitment is one proposed explanation for these observed trends, although the underlying causes remain unknown. To determine if landscape or other habitat changes are affecting the two deer species in different ways, we studied bed-site selection of mule deer and white-tailed deer fawns in western Kansas at microhabitat and landscape scales. We also assessed how fawn intrinsic factors, doe maternal condition, and bed-site habitat characteristics influenced survival of mule deer and white-tailed deer fawns. In February 2018 and 2019, we captured 120 adult does (60 mule deer, 60 white-tailed deer) using helicopter net-gun techniques and deployed 120 vaginal implant transmitters (VITs) synchronized with GPS collars deployed on does. Upon VIT expulsion, a birthing event notification was triggered, which narrowed search efforts for fawns. We captured and radio-collared 100 fawns (53 mule deer, 47 white-tailed deer) during 12 May- 23 June in 2018 and 2019. Fawns were visually located daily using ground-based radio-telemetry and we assessed bed-site selection, cause-specific mortality, and survival rates until fawns reached 10 weeks of age. Overall, fawn survival was low (0.32 ± 0.06) and did not differ between species (mule deer: 0.25 ± 0.08; white-tailed deer: 0.41 ± 0.08). Adult chest girth was positively associated with 70-day white-tailed deer fawn survival, longer fawn body length increased 7-day white-tailed deer fawn survival, and fawn sex best predicted 7-day mule deer fawn survival. Model uncertainty indicated fawn intrinsic factors and maternal conditions may be poor predictors of fawn survival. White-tailed deer survival was lower for fawns with

more woodland in their home ranges and mule deer fawn survival exhibited a positive quadratic relationship with the amount of grassland within the home range. Mule deer fawn survival increased with the amount of edge and disaggregation within a home range, but landscape configuration did not explain survival of white-tailed deer fawns. We analyzed microhabitat characteristics at 2689 fawn bed-sites and 2689 paired random points. Bed-site selection differed by species; however, vegetative structure was the most influential microhabitat characteristic for both deer species. Mule deer fawns selected for 75% visual obstruction 8.4 dm tall, less grass cover, more succulent cover, and 56% shrub cover at bed-sites. White-tailed deer fawns selected for 25% visual obstruction 9.2 dm tall, 71% forest canopy cover, and less grass cover and bare-ground at bed-sites. The two species also showed differences in landscape selection. The odds of a white-tailed deer fawn bed-site increased 5.88 times in woodlands, whereas odds of a mule deer fawn bed-site increased 2.85 times in CRP. Our research suggests white-tailed deer fawns and mule deer fawns selected different characteristics for bed-sites at the microhabitat and landscape scale. Bed-site selection likely influences fawn survival, which could affect fawn recruitment. Managers should focus on maintaining heterogeneous landscapes composed mainly of native and Conservation Reserve Program grasslands with abundant cover to enhance mule deer fawn survival and bolster adult populations.

Table of Contents

List of Figures

List of Tables

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Dedication

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Chapter 1 - Introduction to white-tailed deer and mule deer ecology

Mule deer (*Odocoileus hemionus;* hereafter MD) and white-tailed deer (*O. virginianus*; herafter WTD) are two sympatric deer species in the Great Plains and western United States that have been exhibiting different population trends temporally and spatially. Mule deer populations are declining and undergoing a westward range contraction (Ballard et al. 2001, Shallow et al. 2015) while WTD populations are increasing and expanding to the west (Martinka 1968, Van der Hoek et al. 2002). White-tailed deer easily adapt to anthropogenic changes and have a greater resistance to disease and parasites, possibly bolstering current populations (Austin 2010). Competition with WTD (Ballard et al. 2001, Cooley et al. 2008, Hurley et al. 2011, Krämer 1973), changes in habitat quality and quantity (Ballard et al. 2001, Shallow et al. 2015, Bergman et al. 2014, Brunjes et al. 2006, Cooley et al. 2008, Krämer 1973), and low fawn recruitment (Ballard et al. 2001, Dietz and Nagy 1976, Hamlin et al. 1984, Lomas and Bender 2007, Pojar and Bowden 2004) have all been speculated to influence the decline of MD populations; however, the cause for the decline remains unknown.

Mule deer populations often decline in the presence of increasing WTD populations (Martinka 1968), even though the two species are believed to have minimal interspecific competition due to differences in habitat selection. Mule deer often select open landscapes, native forbs (Avey et al. 2003), and vegetation dominated by Junipers (*Juniperus* spp.; Anthony and Smith 1977, Butler et al. 2009). Mule deer generally select higher elevation (Martinka 1968, Brunjes et al. 2006, Butler et al. 2009), greater percent slope (Lingle 2002, Avey et al. 2003, Butler et al. 2009), and more rugged topography (Swenson et al. 1983) compared to WTD that

select riparian zones (Swenson et al. 1983), dense forests (Avey et al. 2003), or early successional forests and agricultural crops (Nixon et al. 1991).

Similar to broader population trends, deer population structures have been shifting within the state of Kansas over the last 25-50 years. Surveys conducted by the Kansas Department of Wildlife, Parks, and Tourism (KDWPT) show an increase in WTD sightings since 2006 (Figure 1.1), but a decline in percent MD included in hunter harvest (Figure 1.2) and MD observations by bow hunters (Figure 1.3). Direct competition between WTD and MD may play a larger role in structuring Kansas deer populations, because the Central Plains do not offer drastic elevation gradients or large riparian and forested areas commonly responsible for partitioned WTD and MD populations found in other ecosystems.

Changes in land cover have been occurring in Kansas (United States Department of Agriculture; Figure 1.4) with recent changes involving the conversion of native grassland to cropland or woodland, and cropland to Conservation Reserve Program grasslands (Peterson et al. 2004; hereafter CRP). Distinct prairie landscapes have slowly transitioned into heterogeneous landscapes because of agriculture practices, government incentives (e.g., CRP), urban development, and woody encroachment. Woody vegetation, in particular, has increased in the Great Plains because of overgrazing and fire suppression (Van der Hoek et al. 2002). Changes in habitat can cause cascading effects within MD populations, thus influencing physical condition, survival, and reproductive success of deer (Shallow et al. 2015).

Intrinsic characteristics of fawns and their dams influence fawn survival. Doe maternal condition of MD affected fawn birth characteristics, and consequentially, fawn survival in Idaho (Shallow et al. 2015). Measurements of doe nutritional health and litter size also affected MD fawn survival in New Mexico (Lomas and Bender 2007) and Washington (Johnstone-Yellin et

al. 2009). Survival of white-tailed deer fawns varied by sex and birth mass in in Louisiana (Shuman et al. 2017) and sex in Minnesota (Carstensen et al. 2009).

Mule deer and WTD fawns are capable of long movements (>1 km) within the first 30 days of life (Riley and Dood 1984, Grovenburg et al. 2012); however, fawns 3-6 weeks postpartum typically limited movement and relied heavily on hiding as a predator avoidance strategy in Texas (Butler et al. 2009). Within the first two months of life, neonates are most susceptible to death from natural causes or predation (Grovenburg et al. 2010). In a system where visual searching predators are present, natural selection likely benefits bedded fawns that restrict movement and rely on cryptic coloration for passive camouflage (Gerlach and Vaughan 1991). This suggests bed-site selection plays a crucial role in fawn survival and ultimately can affect fawn recruitment rates.

Survival rates (3–6 months) of WTD fawns in North America ranged from 0.14 to 0.90 (Gingery et al. 2018) whereas MD fawn survival rates have been reported as low as 0.00 in New Mexico (Lomas and Bender 2007) to 0.59 in Colorado (Pojar and Bowden 2004). Fawn survival rates and cause-specific mortality are essential components to understanding population dynamics (Brinkman et al. 2004, DelGiudice et al. 2007). In North Carolina, fawn survival was the most crucial vital rate influencing population growth (λ) in WTD (Chitwood et al. 2015). Deer population dynamics are guided by the synergy between highly variable juvenile and fairly constant adult survival rates (Lomas and Bender 2007), suggesting factors influencing fawn survival may help project future population trends (Shallow et al. 2015).

The purpose of this thesis is to study WTD and MD fawns to understand if fawn survival and bed-site selection play a significant role in the disparate population trends observed between two sympatric deer species in western Kansas. Western Kansas provides an opportunity to study

WTD and MD in a rangeland/cropland mosaic where the species likely interact more and have less of an opportunity to segregate compared to other ecosystems.

In Chapter 2, I compare fawn bed-site selection between WTD and MD at the microhabitat and macrohabitat scales. I show that both species select different bed-sites at the microhabitat and macrohabitat scales, but that the two species still have some common habitat requirements.

In Chapter 3, I explore fawn survival related to fawn intrinsic values, adult capture measurements, microhabitat vegetation, land cover composition, and land cover configuration. I show that microhabitat characteristics at fawn bed-sites and land cover composition and configuration within fawn home ranges influence fawn survival in WTD and MD. I also show fawn intrinsic qualities contribute little to fawn survival in Kansas.

In Chapter 4, I compile my conclusions from Chapters 2 and 3. I relate bed-site selection to fawn survival, discuss future management implications, and provide some insight for future research.

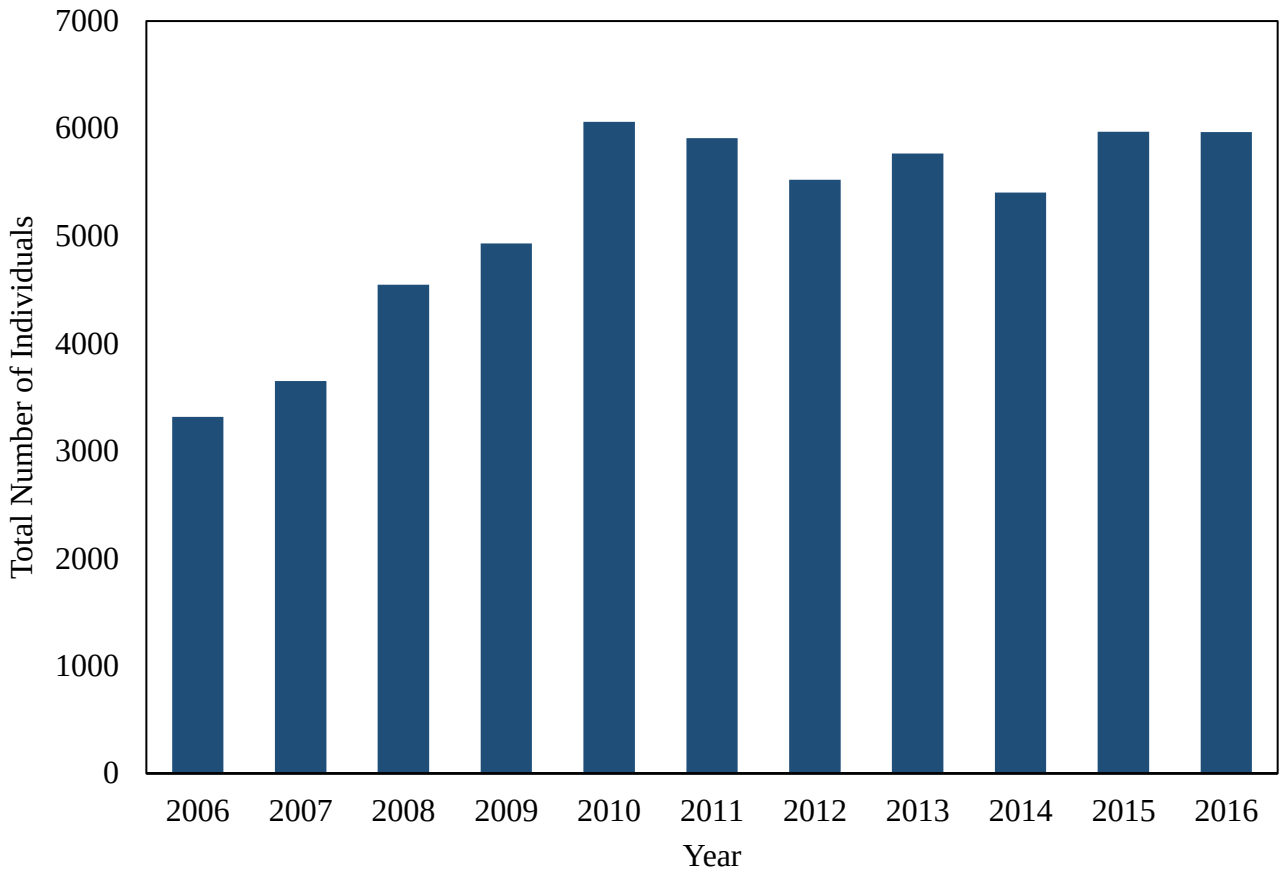

Figure 1.1 Total number of individual white-tailed deer observed in Kansas during annual spotlight surveys conducted by the Kansas Department of Wildlife, Parks, and Tourism from 2006 to 2016.

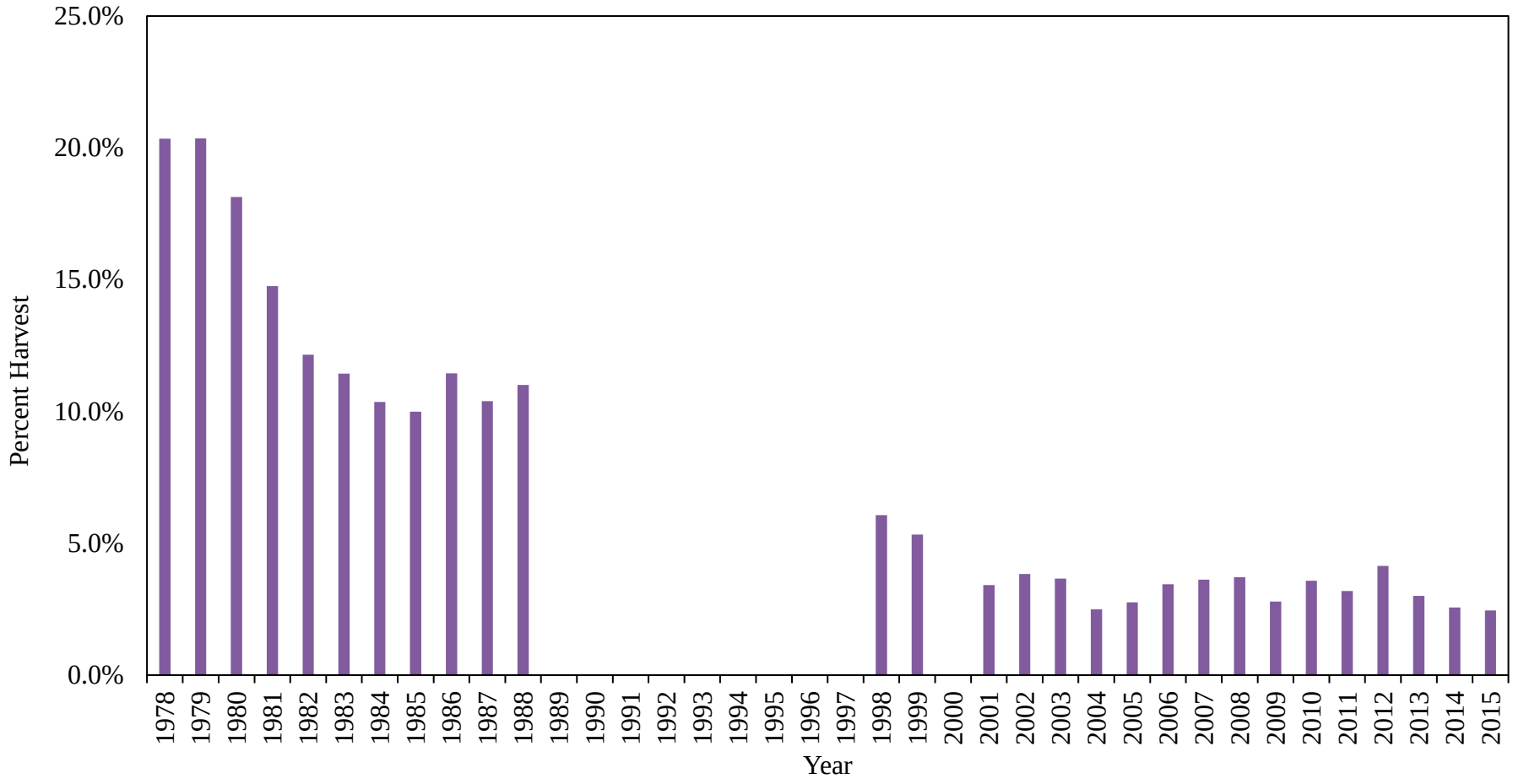

Figure 1.2 The percent annual hunter harvest composed of mule deer within Kansas from 1978-2015.

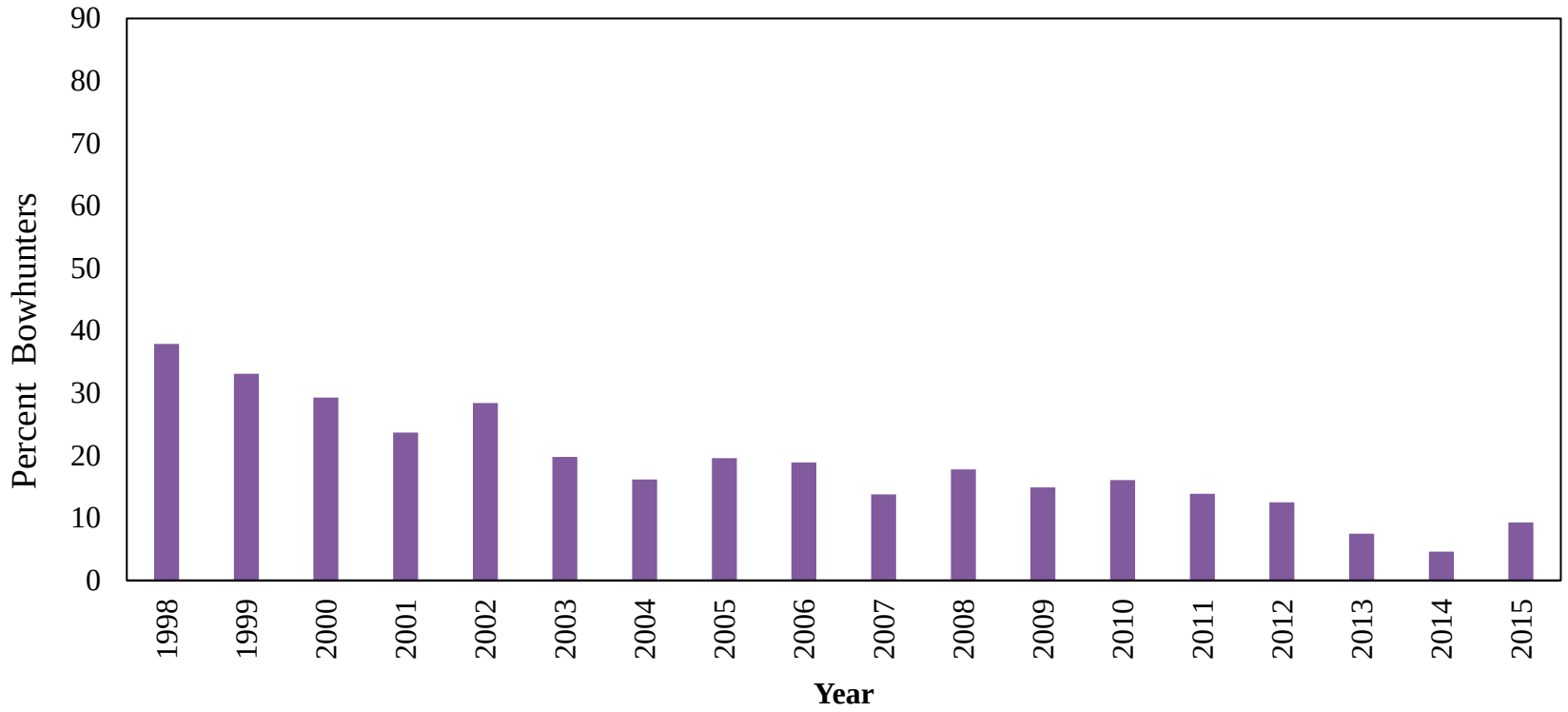

Figure 1.3 The percent of bow hunters observing mule deer within the eastern geographic range of mule deer in Kansas from 1998-2015.

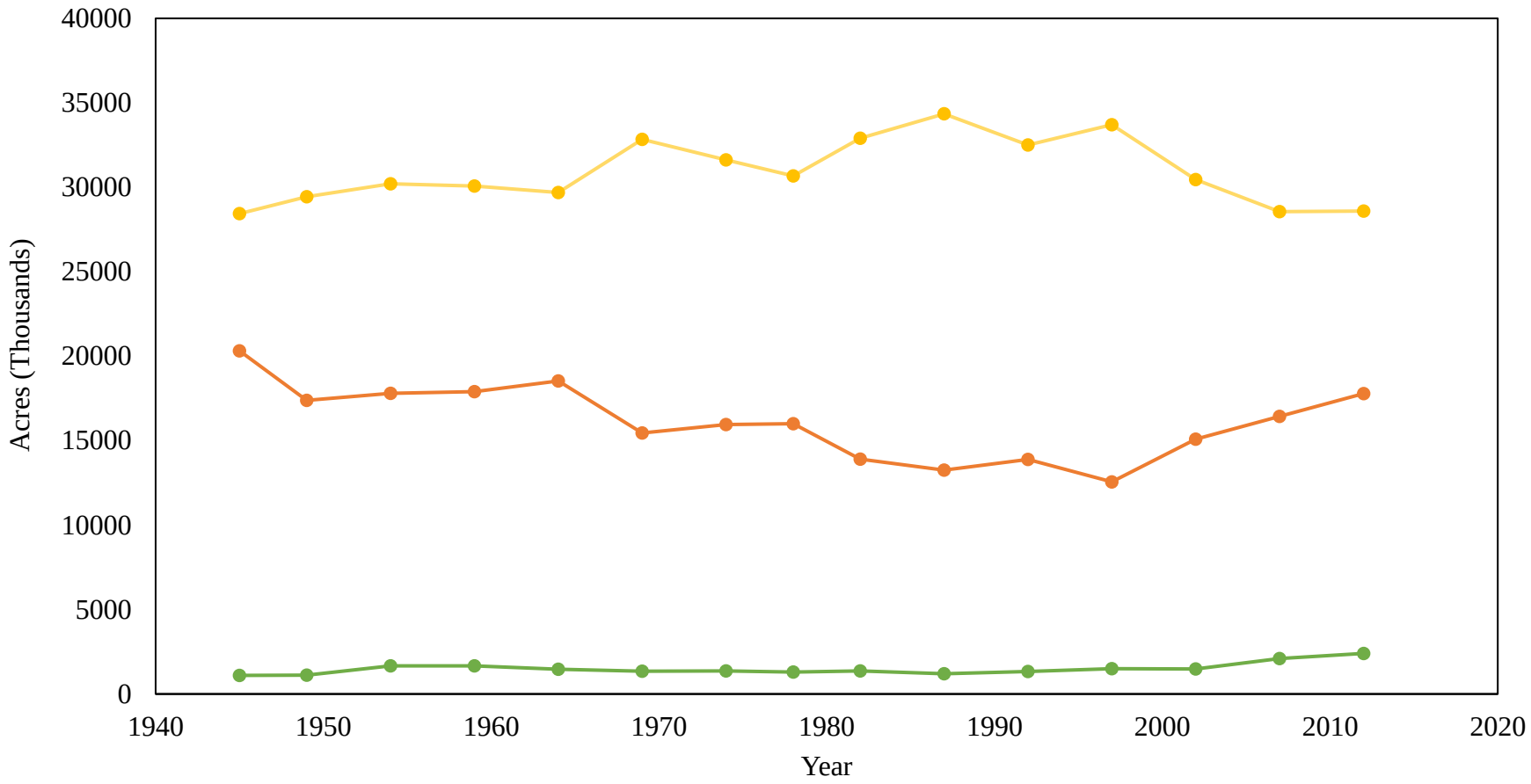

Figure 1.4 Historic land use changes in cropland (yellow), grassland pasture and range (orange), and forest-use land (green) in Kansas between 1945–2011 (USDA 2012).

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Chapter 2 - Bed-site selection by white-tailed deer and mule deer fawns in Western Kansas

Abstract

Mule deer (*Odocoileus hemionus*) and white-tailed deer (*O. virginianas*) populations have exhibited divergent population trends in the Central Great Plains, potentially because of dissimilar fawn recruitment rates. Fawn movement is limited during the first few weeks of life and they rely on available vegetation for thermal cover and predator avoidance, which influence survival rates and population dynamics. We collared 47 white-tailed deer fawns and 53 mule deer fawns in western Kansas and collected 2689 used and 2689 random vegetation points between May and August during 2018 and 2019. Microhabitat characteristics at fawn bed-sites differed between species. Vegetative structure was the most important habitat feature for bed-site selection by both species. White-tailed deer fawns selected bed-sites with 25% visual obstruction 9.2 dm tall, 71% forest canopy cover, and less canopy cover of grass and bare-ground compared to random sites. Mule deer fawns selected bed-sites with 75% visual obstruction 8.4 dm tall, 56% shrub cover, greater succulent cover, and less grass cover than random sites. Bed-site selection also differed at the landscape scale. White-tailed deer fawns selected bed-sites in woodlands while mule deer fawns selected bed-sites in Conservation Reserve Program grasslands (CRP). Differences in fawn bed-site selection between the two species could influence fawn survival rates and may ultimately explain dissimilar adult population trends observed in white-tailed deer and mule deer in western Kansas. Our research suggests increasing woodland and CRP cover on the landscape containing relatively dense vegetation cover between 8–10 dm tall would provide adequate bed-sites for WTD and MD fawns, respectively.

Introduction

Mule deer (*Odocoileus hemionus*; hereafter MD) and white-tailed deer (*O. virginianus*; hereafter WTD) are two sympatric deer species in the Great Plains and western United States that have been exhibiting different population trends temporally and spatially. Spotlight surveys, bow hunter observations, and deer harvest species composition in Kansas indicate WTD abundance has increased since 2006 while MD have decreased since 1998 (Kansas Department of Wildlife, Parks, and Tourism; Chapter 1). Low fawn recruitment (Ballard et al. 2001, Dietz and Nagy 1976, Hamlin et al. 1984, Lomas and Bender 2007, Pojar and Bowden 2004) is one speculated cause of the decline of MD populations; however, the ultimate cause of the decline remains unknown.

Bed-site selection may play a vital role in fawn recruitment and overall population trends by influencing fawn survival. Although the adult doe chooses an initial birthing area, fawns are capable of selecting specific bed-sites within the home range of the maternal doe (Grovenburg et al. 2010, Butler et al. 2009). Vegetation cover can play an influential role on fawn mortality because fawns are most susceptible to death from natural causes within the first two months of life (Grovenburg et al. 2010). Vegetation cover at bed-sites conceals fawns that rely on cryptic coloration for passive camouflage, thereby reducing predatory pressure and increasing overall survival (Gerlach and Vaughan 1991). Additionally, vegetation structure at bed-sites can provide thermal insulation and protection from weather elements, allowing fawns to limit energy expenditure on thermoregulation and possibly increase survival (Grovenburg et al. 2012b).

Previous studies showed differences in bed-site characteristics between the two deer species. Mule deer fawns selected bed-sites at higher elevations and steeper slopes, with less

vegetative hiding cover than WTD fawns in Texas (Butler et al. 2009). In a pinyon (*Pinus edulis*)-juniper (*Juniperus monosperma*) setting in Colorado, 76% of MD fawn bed-sites occurred in shrubby draws, likely because of denser vegetation (Gerlach and Vaughan 1991) and topographic features that provided concealment cover. Mule deer fawns in Montana used wheatgrass (*Agropyron smithii, A. spicatum*) interspersed with sagebrush (*Artemisia tridentate*) and greasewood (*Sarcobatus vermiculatus*) initially, but switched to juniper (*Juniperus scopulorum*) mixtures containing Douglas-Fir (*Psudotsuga menziesii*) and Pine (*Pinus ponderosa*) later in the summer (Riley and Dood 1984). In Texas, MD fawns bedded under junipers (*Juniperus* sp.) more frequently than WTD fawns that commonly bedded under honey mesquites (*Prosopis glandulosa*) and herbaceous vegetation (Butler et al. 2009). White-tailed deer fawns selected tallgrass Conservation Reserve Program (hereafter CRP) grasslands more than pasture, alfalfa, wheat, and forested cover for bed-sites in the Northern Great Plains (Grovenburg et al. 2010). White-tailed deer fawns selected CRP vegetation early in the summer and shifted resource selection to focus on corn towards the end of summer while still using CRP (Grovenburg et al. 2012a). Bed-sites of WTD fawns in Iowa contained more woody cover than was available (Huegel et al. 1986). An increase of 1 cm in understory vegetation height increased the odds of a bed-site by 3.5% in woodlands in South Dakota (Grovenburg et al. 2010). It is likely fawns selected vegetation at bed-sites by prioritizing enhanced security cover over food because fawns have underdeveloped digestive systems during the early stages of life and depend on quality milk from lactating does, rather than foraging, to survive (Tollefson et al. 2011). Previous studies demonstrated bed-sites qualities differed between MD and WTD fawns; therefore, fawn bed-site characteristics likely differ between the two species in Kansas.

To explore resource selection at fawn bed-sites in Kansas, our objectives were to 1) assess fawn bed-site selection for WTD and MD at the micro- and macrohabitat scales, and 2) determine if bed-site selection differed between MD and WTD fawns. We predicted that vegetative structure (measured as visual obstruction) would be the most influential microhabitat feature for bed-site selection, as fawns rely heavily on vegetation cover and cryptic coloration for predator avoidance. We predicted both species would use areas that had greater cover within the 0.0–5.0 dm range; a height we felt was more than adequate to hide a bedded fawn. Moreover, we predicted WTD fawns would select bed-sites with more forest canopy cover than MD, because of the tendency for WTD to select forested landscapes.

Study Area

We captured WTD and MD fawns and recorded bed-site composition at two study sites in eight counties located in western Kansas. The North site (~85,000 ha) occurred in Graham, Norton, Sheridan, and Decatur counties and was ~148 km from the South site (~137,000 ha), which resided in Lane, Gove, Scott, and Logan counties (Figure 2.1).

Both study sites were located in the Central Great Plains and High Plains level III ecoregions (U.S. Environmental Protection Agency). Summer (May-August) temperatures at the North site ranged from 6.7–40.6 ˚C and -1.0–42.2 ˚C with 598.0 mm and 584.5 mm total summer precipitation in 2018 and 2019, respectively (Hill City Municipal Airport, KS, US, National Oceanic and Atmospheric Administration [NOAA], 2019). Summer temperatures at the South site ranged from 3.9–39.4 ˚C and -1.7–39.4 ˚C with 427.8 mm and 315.8 mm total summer precipitation in 2018 and 2019, respectively (Scott City, KS, USA, NOAA, 2019). We experienced abnormally wet summers during our study compared to the previous 20 years when

total summer precipitation averaged 288.80 mm ± 100.58 and 275.84 mm ± 81.79 per year for the North and South study site, respectively.

The landscape was mostly flat with rolling hills and shallow ravines. The North Fork of the Solomon River ran through the center of the North study site and the Smoky Hill River bordered the South site. Agriculture was the dominant land use in both study sites, which were mostly composed of grazed rangelands and row crop agriculture. The North site consisted of 53.3% cropland, 37.6% grassland, 6.2% Conservation Reserve Program (CRP), 2.3% woodlands, and 0.6% urban and the South site contained 45.3% cropland, 45.1% grassland, 7.7% CRP, 1.2% woodland, and 0.7% urban. Corn (*Zea mays*), wheat (*Triticum aestivum*), and milo (*Sorghum bicolor*) dominated agricultural crops, while alfalfa (*Medicago sativa*), soybeans (*Glycine max*), and sunflowers (*Helianthus annuus*) occurred less often. Grasslands consisted of native mixed-grass prairie primarily grazed by cattle, while CRP lands consisted of un-grazed tallgrass prairie species including big bluestem (*Andropogon gerardi*), switchgrass (*Panicum virgatum*), and Indiangrass (*Sorghastrum nutans*). Woodlands within close proximity to fawn bed-sites included a riparian area along the Solomon River at the North site, but also included shelterbelts and dispersed tree clusters. Common grasses included little bluestem (*Schizachyrium scoparium*), buffalo grass (*Bouteloua dactyloides*), and blue grama (*Bouteloua gracilis*). Broom snakeweed (*Gutierrezia sarothrae*), common mullein (*Verbascum thapsus*) and tall thistle (*Cirsium altissimum*) were typical forbs, and prevalent succulents included yucca (*Yucca glauca*) and prickly pear cactus (*Opuntia macrorhiza*). Common tree species included American elm (*Ulmus americana*), hackberry (*Celtis occidentalis*.), black cherry (*Prunus serotina*), eastern cottonwood (*Populus deltoides*), honey locust (*Gleditsia triacanthos*), black walnut (*Juglans nigra*),

mulberry (*Morus rubra*) and eastern red cedar (*Juniperus virginiana*). Plum thickets (*Prunus* angustifolia) and smooth sumac (*Rhus glabra*) were frequent shrubs in western Kansas.

Methods

Adult Capture

We captured, collared, and processed 30 MD and 30 WTD adult does, annually, at each study site during February 2018 and 2019 (n = 120). Helicopter capture crews (Quicksilver Air Inc, Fairbanks, AK) captured adult does utilizing net-gun capture techniques, administered light sedation (15 mg Butorphanol [50mg/ml], 15 mg Azaperone [50mg/ml], and 15 mg Midazolam [50mg/ml]), and transported deer to a central location for processing (<5 km from capture location). All animal handling procedures were compliant with standards for field studies established by the American Society of Mammologists (Sikes et al. 2016), approved by the Institutional Animal Care and Use Committee at Kansas State University (protocol 3963), and authorized under the state of Kansas scientific, education, or exhibition wildlife permits (SC-024-2018, SC-015-2019).

We measured rump and loin fat reserves (Cook et al. 2001) and determined pregnancy status of does with a portable handheld ultrasound (IBEX PRO/r, E.I. Medical Imaging, Loveland, CO). Pregnant does were fitted with 731g VERTEX Plus GPS collars (Vectronic Aerospace GmbH, Berlin, Germany) and received a 30g vaginal implant transmitter (VIT; Vectronic Aerospace GmbH, Berlin, Germany). Collars recorded hourly GPS locations, synchronized to VITs via Ultra-High Frequency (UHF), and sent VIT expulsion notifications via text and email through the Iridium satellite network if a suspected parturition event occurred. Collars sent expulsion notifications if VIT temperature dropped ≤34˚C for 50 minutes or if the activity sensor failed to register any activity over a 5-minute span.

Fawn Capture and Monitoring

Upon receiving a VIT parturition notification, we used GPS Plus X (v.10.4.8, Vectronic) software to determine the VIT location. We waited 3 hours after receiving a parturition notice before investigating the suspected VIT location to allow bonding between the doe and fawn. Once the VIT was located, we searched ≤ 2 hours to locate fawns. We processed fawns 15-20 m from their capture location to limit disturbance to the bed-site. All personnel wore nitrile gloves during capture to limit the transfer of human scent. Furthermore, we wore rubber boots during capture and monitoring efforts in 2019 to minimize scent transfer to the surrounding vegetation. We fitted fawns with 56g expandable VHF/UHF fawn collars (Vectronic Aerospace GmbH, Berlin, Germany), applied one plastic ear tag (Button Combo, Y-TEX, Cody, WY) and one metal ear tag (Style 505, National Band & Tag Company, Newport, KY), and recorded morphological measurements during capture. We returned fawns to their original capture location and limited handling time ($\bar{x}$ =10 minutes) to minimize stress on both does and fawns.

We visually located fawns daily via VHF homing up to 10-weeks after capture. We recorded the fawn's bed-site location with a handheld GPS unit (Map 64st, Garmin, Olathe, KS), and measured microhabitat characteristics at the bed-site the following day to limit disturbance to the fawn. We measured tree canopy cover with a convex densiometer (Lemmon 1956; Forestry Suppliers, Inc., Jackson , MS), herbaceous canopy cover of six plant functional groups (grass, forb, shrub, bare, succulent, and litter) with a 25 x 50 cm Daubenmire frame (Daubenmire 1959), and visual obstruction with a 13-dm Robel pole (Robel et al. 1970) using a modified approach. Our modified approach included measurements of 0, 25, 50, and 75 percent visual obstruction in addition to the standard 100 percent visual obstruction. Additionally, within each

Daubenmire frame, we recorded litter depth (in the upper right corner) and height of the tallest vegetation. At each habitat assessment point, we estimated four forest canopy cover, four visual obstruction, and eight herbaceous canopy cover readings. We recorded one forest canopy cover, one visual obstruction, and one herbaceous canopy cover reading in each cardinal direction, 4 m from the bed-site. We took an additional herbaceous canopy cover reading in each cardinal direction adjacent to the center of the bed-site. We randomly generated a point 300 m away from each bed-site location (R Core Team 2019), and assessed the same habitat characteristics at that location (non-use location).

Analysis

We conducted all analyses in R (version 3.6.1, R Core Team 2019). We *z*-transformed all microhabitat covariate values prior to fitting models to allow comparison among covariates with different ranges and units of measure. Vegetation height was collinear ($|r| \geq 0.5$) with all visual obstruction measurements and removed from the data set. We retained visual obstruction instead of vegetation height, because visual obstruction provides information on both vegetation height and density and is a more comprehensive metric of vegetative structure.

We used logistic regression (lme4 package; v 1.1-21; Bates et al. 2015) to assess habitat characteristics important for bed-site selection. We included doe ID as a random effect to account for a potential lack of independence in habitat selection among twin fawns. We initially ran a suite of univariate models with linear and quadratic functions of all microhabitat variables and selected the most supported model based on Akaike's Information Criterion adjusted for small sample size (AICc; AICcmodavg v.2.2-2; Mazerolle 2019). We used the top results for

each individual variable (i.e., quadratic or linear model) from the univariate model suite to create multivariate models associated with our *a priori* hypotheses.

To evaluate macrohabitat selection, we created a ground-truthed map in a geographic information system (GIS; ArcMap v.10.6, Esri, Redlands, CA) to represent the land cover for both study sites. We classified land cover into one of six categories: grassland, cropland, woodland, CRP, urban, and water. We extracted the land cover category from the land cover map in GIS to each measured vegetation point (i.e., fawn bed-site locations and random points). We used general linear mixed effects models to run our macrohabitat selection analysis with Doe ID as a random effect. We ran a univariate model suite for MD and WTD fawns separately to determine macrohabitat characteristics that best predicted fawn bed-sites for each species. We used beta coefficients from each species' model suite to determine strength of selection between different land cover categories.

Results

We captured 53 MD fawns and 47 WTD fawns from 120 VITs during 12 May to 25 June 2018 and 2019. We analyzed microhabitat variables at 2689 bed-sites (1,395 MD, 1,294 WTD) and 2689 random vegetation points located 300m away.

Microhabitat characteristics differed between bed-sites and random points for both species (Table 2.1). White-tailed deer fawn bed-sites had greater canopy cover of grass ($F_{1,2586}$ = 19.53, $p < 0.001$), forb ($F_{1,2586} = 50.77$, $p < 0.001$), shrub ($F_{1,2586} = 36.43$, $p < 0.001$), succulent ($F_{1,2586} = 4.30$, $p = 0.038$), and greater vegetation height ($F_{1,2586} = 239.80$, $p < 0.001$), litter depth ($F_{1,2586} = 62.81$, $p < 0.001$), forest canopy cover ($F_{1,2586} = 162.80$, $p < 0.001$), and visual obstruction at all obstruction levels (0% obstruction, $F_{1,2580} = 491.90$; 25%, $F_{1,2580} = 426.80$; 50%,

$F_{1,2580}$ = 369.70; 75%, $F_{1,2580}$ = 308.80; 100%, $F_{1,2580}$ = 230.30; $p < 0.001$) than random points. Cover of bare ground ($F_{1,2583}$ = 200.8, $p < 0.001$) and litter ($F_{1,2589}$ = 14.78, $p < 0.001$) were less at WTD fawn bed-sites than random sites. Mule deer fawn bed-sites consisted of greater visual obstruction at all levels (0% obstruction, $F_{1,2788}$ = 343.40; 25%, $F_{1,2788}$ = 360.60; 50%, $F_{1,2788}$ = 365.20; 75%, $F_{1,2788}$ = 368.00; 100%, $F_{1,2788}$ = 351.60; $p < 0.001$) and contained greater ground cover of forb ($F_{1,2788}$ = 16.70, $p < 0.001$), shrub ($F_{1,2788}$ = 142.80, $p < 0.001$), and succulent ($F_{1,2788}$ = 10.95, $p < 0.001$) compared to random sites. Mule deer fawn bed-sites also had greater vegetation height ($F_{1, 2787}$ = 142.10, $p < 0.001$), forest canopy cover ($F_{1, 2784}$ = 30.15, $p < 0.001$), and litter depth ($F_{1, 2788}$ = 43.02, $p < 0.001$) compared to random points; but had less grass cover ($F_{1, 2788}$ = 55.19, $p < 0.001$). There were no differences between percent bare ground ($F_{1, 2788}$ = 0.022, $p = 0.88$) or percent litter cover ($F_{1, 2788}$ = 3.50, $p = 0.06$) between used and available sites for mule deer fawns.

Microhabitat characteristics at bed-sites also varied between species (Table 2.1). White-tailed deer fawn bed-sites had greater visual obstruction (0% obstruction, $F_{1,2681}$ = 157.10; 25%, $F_{1,2681}$ = 55.90; 50%, $F_{1,2681}$ = 30.05; 75%, $F_{1,2681}$ = 24.40; 100%, $F_{1,2681}$ = 16.27; $p < 0.001$), grass cover ($F_{1,2687}$ = 58.46, $p < 0.001$), litter cover ($F_{1,2687}$ = 25.41, $p < 0.001$), vegetation height ($F_{1,2686}$ = 142.50, $p < 0.001$), litter depth ($F_{1,2687}$ = 34.73, $p < 0. 001$) and forest canopy cover ($F_{1,2683}$ = 329.70, $p < 0.001$) than MD fawn bed-sites. We observed more percent shrub ($F_{1,2687}$ = 58.12, $p < 0.001$), percent bare ground ($F_{1,2687}$ = 106.50, $p < 0.001$), and percent succulent cover ($F_{1,2687}$ = 50.41, $p < 0.001$) at MD fawn bed-sites compared to bed-sites selected by WTD fawns and did not detect differences in forb cover ($F_{1,2687}$ = 0.22, $p = 0.64$) among bed-sites of the two species.

The top univariate bed-site selection model for each species included visual obstruction, but the percent obstruction varied among species. Quadratic visual obstruction at 25% obstruction best explained WTD fawn bed-sites (Table 2.2), while quadratic visual obstruction at the 75% obstruction level represented MD fawn bed-sites (Table 2.3). Visual obstruction at all obstruction levels outranked all other models (ie. grass, forb, etc), for both species.

The top multivariate bed-site selection model for MD fawns contained visual obstruction (75%), and canopy cover of shrub, grass, and succulent (Table 2.5). Predictions from the highest ranked model showed MD fawns selected bed-sites with visual obstruction 8-10 decimeters tall, up to 56% shrub cover, more succulent cover, and less grass cover (Figure 2.2). The top multivariate bed-site selection model for WTD fawns included visual obstruction (25%), bare-ground, forested canopy cover, and grass canopy cover and there were no competing models (Table 2.4). Predictions from the top model revealed optimal bed-site selection for WTD occurred at 8-10 decimeters of visual obstruction, up to 71% forest canopy cover, and lower percent cover of grass and bare-ground (Figure 2.3).

Bed-site selection of macrohabitat differed between species. Of WTD fawn bed-sites, 30.27% (n = 392) occurred in grasslands, 29.03% (376) in CRP, 24.71% (320) in woodlands, 15.83% (205) in cropland, 0.15% (2) in urban areas. A majority of MD fawn bed-sites, 69.95% (973), occurred in grasslands, 15.96% (222) in CRP, 9.20% (128) in cropland, 4.89% (68) in woodlands, and 0.00% (0) in urban areas. Mule deer fawns selected for CRP and woodlands, but against croplands and grasslands (Figure 2.4). Similarly, WTD fawns selected for woodlands and CRP, and selected against urban areas, croplands, and grasslands (Figure 2.5). Top univariate land cover models revealed WTD fawns selected bed-sites in woodlands ($\beta = 1.77 \pm 0.15$; Table 2.6) and MD fawns selected bed-sites in CRP ($\beta = 1.04 \pm 0.13$; Table 2.7).

Discussion

We found that MD and WTD fawns in western Kansas selected for bed-sites with greater cover (measured as visual obstruction) compared to available habitat during our two-year study, concurring with previous findings (Hyde et al. 1987, Moorter et al. 2009, Grovenburg et al. 2010,). Visual obstruction was the top-ranked univariate model for both species and present in all top multivariate models. This supports our hypothesis that cover was the most important microhabitat characteristic for fawns selecting bed-sites and is likely due to vegetation providing thermal cover (Moorter et al. 2009) and concealment from predators (Grovenburg et al. 2010); both of which are essential to fawns during the early stages of life (Chapter 3).

Vegetative structure was the best predictor of fawn bed-sites, but MD fawns selected for denser cover than WTD fawns (Figures 2.2, 2.3). Dissimilarities in cover density could pertain to different movement behaviors exhibited by the two species. The stotting gait of MD allows for greater maneuverability compared to the galloping gait of WTD, which produces speed rather than agility (Lingle and Pellis 2002). While fawns of both species rely on cryptic coloration and static movement at bed-sites to avoid predation, the risk of predation of WTD fawns increases in thick understory vegetation (Shuman et al. 2017). It is possible MD fawn stotting allows the species to take advantage of greater concealment offered by denser vegetation, while not sacrificing escape mobility. Although MD fawns selected bed-sites with denser cover, vegetative height was shorter at MD fawn bed-sites compared to WTD fawn bed-sites (Table 2.1) similar to Butler et al. (2009). A functional tradeoff between predator concealment cover and escape mobility for fawns could explain observed differences in vegetation height and density between the two species. Even though WTD and MD fawns selected different vegetation structure (height

and visual obstruction; Table 2.2), both species selected vegetation taller than a bedded fawn (Butler et al. 2009; $\bar{x}$ = 58 cm for WTD, $\bar{x}$ = 41 cm for MD) underscoring the importance of concealment cover.

We observed greater percent cover of grass, forb, shrub, succulent and forest canopy cover, but less bare-ground and litter cover at WTD fawn bed-sites than was available in each study area. Huegel et al. (1986) observed similar selection patterns for vegetation density, forest canopy cover, and percent shrubs, but recorded less percent cover of short/medium forbs and tall grass conflicting with our results. This may be due to differences in sampling methods and scale of measurement between studies. Huegal et al. (1986) classified plant functional groups into short, medium, and tall categories, and we did not. Moreover, we assessed random sites 300 m away, and Huegal et al. (1986) recorded random sites within 10 m of the bed-site. Relationships between use and availability for vegetation height and percent grass cover were similar to those from South Dakota (Uresk et al. 1999); however, canopy cover results were different because WTD fawn bed-sites in South Dakota had less canopy cover than was available. Thinned pine stands in South Dakota (less canopy cover) and riparian areas in western Kansas (more canopy cover) both provided dense herbaceous understory cover, which likely influenced bed-site selection more rather than the actual canopy cover itself.

Mule deer fawn bed-sites consisted of greater vegetative structure, forest canopy cover, and canopy cover of shrubs compared to available locations in western Kansas similar to MD fawn bed-sites in Colorado (Gerlach and Vaughan 1991). Kansas MD fawns also selected greater canopy cover of forbs and succulents, but less grass cover at bed-sites than available, which was not reported in Colorado. Differences in selection between the two studies may suggest greater heterogeneity at fawn bed-sites in Kansas. Native plant species diversity and species richness are

greater in grazed than non-grazed prairies (Hickman et al. 2004). The heterogeneous mixture of vegetation at fawn bed-sites in Kansas may have resulted from different grazing intensities, as cattle were present in Kansas during both study years and only one year in the Colorado study.

White-tailed deer selected different bed-site microhabitat characteristics than mule deer. We observed greater bare ground cover, and less vegetative structure, forest canopy cover, vegetation height, and grass canopy cover at MD fawn bed-sites compared to WTD fawn bed-sites; suggesting MD fawns bedded down in more open habitat compared to WTD fawns. Mule deer fawns in Texas also bedded in shorter hiding cover compared to WTD fawns that bedded in herbaceous vegetation (Butler et al. 2009). We also recorded greater cover of succulents and shrubs at MD fawn bed-sites compared to WTD fawn bed-sites. It is likely shrubs and succulents at MD fawn bed-sites in open grassland habitat functioned similarly (i.e. provided concealment and thermal cover) to dense vegetation understories located in CRP and woodlands, which comprised ~54% of WTD fawn bed-sites.

Top bed-site selection models predicted MD and WTD fawns would select bed-sites with less grass canopy cover and relatively dense vegetation structure up to 8-10 dm. Decreasing trends in grass canopy cover combined with multiple additional covariates in each species' top respective bed-site selection model, suggests fawns selected for some degree of heterogeneity at bed-sites. White-tailed deer fawns selected bed-sites with greater tree canopy cover, supporting our hypothesis that WTD fawns would select bed-sites with greater wooded canopy than MD fawn bed-sites. Although not specified, we expected a linear relationship with forest canopy cover rather than a quadratic relationship where selection intensity tapered as tree canopy cover increased (Figure 2.3). Greater tree canopy cover likely resulted in reduced vegetative structure in the understory, leading to limited concealment cover for fawns. Additionally, fawn age may

be partially responsible for this tapering effect as older fawns select less canopy cover (Grovenburg et al. 2010), however, we did not include age in our selection models. Our top model also predicted WTD fawns selected bed-sites with minimal bare-ground composition; bolstering the importance of herbaceous cover at fawn bed-sites.

Mule deer fawns selected bed-sites with 56% shrub cover and probability of selection increased with succulent cover. Mule deer are generally associated with areas containing higher elevations (Martinka 1968, Brunjes et al. 2006, Butler et al. 2009), greater percent slopes (Lingle 2002, Avey et al. 2003, Butler et al. 2009), and more rugged topography (Swenson et al. 1983) compared to sympatric WTD. Kansas lacks extreme elevation gradients prevalent in the western U.S.; however, rocky ravines in pastures with scattered shrubs and succulents are available in western Kansas. The majority (69.95%) of MD bed-sites were located in grazed grasslands with limited concealment cover, suggesting that shrubs and succulents are likely providing vegetative cover needed by fawns for concealment.

Fawn bed-site selection at the macrohabitat scale also differed between WTD and MD. Presence of CRP best predicted bed-site selection of MD fawns, with the odds of a bed-site increasing 2.85 times if the land cover type was CRP. Grovenburg et al. (2010) found similar results for WTD fawns in South Dakota and suggested fawns selected CRP for vertical structure in landscapes dominated by agriculture. Conservation Reserve Program grasslands in Kansas were comprised of tall-grass prairie mixtures native to eastern Kansas. CRP provided tall and dense vegetation cover that was historically provided by native mixed-grass prairie; however, this vegetative cover is currently absent in mixed-grass prairie because of current grazing management practices. Although CRP was the best predictor of MD fawn bed-sites, only 16% of bed-sites occurred in CRP and CRP land cover was scarce at our study sites (~7%). The majority

of MD fawn bed-sites (~70%) occurred in mixed-grass prairie. Therefore, the importance of MD fawns selecting bed-sites in CRP is likely because of the vegetation cover it offers on a landscape where cover is already limited, rather than selecting a land cover that was not historically available to mule deer.

White-tailed deer fawns selected for bed-sites located in limited woodlands that are available in western Kansas. The odds of a WTD fawn bed-site was 5.88 times greater in a woodland land cover, which is likely due to adult WTD selecting riparian (Swenson et al. 1983) or forested (Avey et al. 2003, Nixon et al. 1991) areas. Large forested landscapes near WTD fawn capture locations in Illinois provided adequate concealment from predators while numerous adjacent small forest patches allowed easier access to additional resources (Rohm et al. 2007). Our findings were similar to those from Michigan (Hiller et al. 2007) where WTD fawns used proportions of conifer and lowland deciduous forests greater than available, but different from Grovenburg et al. (2010) who showed WTD fawns selected bed-sites in CRP in South Dakota. Stronger selection for woodlands at WTD fawn bed-sites in Kansas, compared to South Dakota, likely relates to woodlands including a small riparian area in the North site with dense understory vegetation along the Solomon River in Kansas; whereas, South Dakota woodlands consisted only of shelterbelts and planted trees. Although WTD were selecting for bed-sites in woodlands in Kansas, greater woodland composition within the home range of WTD fawns had a negative effect on fawn survival (Chapter 3).

Although not shown in the results, we additionally wanted to understand macrohabitat bed-site selection where WTD and MD co-occurred on the landscape (South site) versus where the two species were more segregated (North site) due to a riparian zone. Land cover selection at the North site concurred with overall land cover selection results for both species, but MD and

WTD fawns at the South site failed to have a definitive model outranking the null model. This suggests woodlands in the North site may segregate WTD and MD fawn bed-sites, and competition between the two species could increase in landscapes where woodlands are not accessible due to similarities in land cover selection. However, it is possible that microhabitat features or the juxtaposition of land cover types in the landscape mosaic could play a more dominant role in fawn bed-site selection rather than the land cover type in the South site.

Bed-site selection differed between MD and WTD fawns at the microhabitat and macrohabitat scale. Fawns are capable of selecting bed-sites, but are limited to the landscape chosen by the maternal doe (Huegel et al. 1986, Butler et al. 2009, Grovenburg et al. 2010). Thus, it is possible fawns have greater influence on bed-site selection at the microhabitat scale rather than the macrohabitat scale. Despite differences in land cover selection, we found WTD fawns and MD fawns selected for greater cover at bed-sites compared to what was available at the microhabitat scale. Habitat variables in Kansas could prove important, as numerous studies have shown that bed-site selection influences fawn survival (Shuman et al. 2017, Chitwood et al. 2015, Grovenburg et al. 2010). It is likely selection for more cover at fawn bed-sites would enhance fawn survival because fawns rely heavily on cryptic coloration (Grovenburg et al. 2010, Chitwood et al. 2015) and concealment cover (Gerlach and Vaughan 1991) for protection from visual searching predators during the early stages of life.

Management Implications

Regardless of land cover, we suggest managing habitats to ensure adequate herbaceous cover, especially during early summer when fawns are most abundant on the landscape and vulnerable to predators. We encourage landowners to implement cattle grazing systems that

promote heterogeneity in vegetation height and density, capable of providing fawn cover. We suggest enrolling and sustaining more CRP grassland to provide additional concealment cover as an alternative to croplands. Precision agriculture techniques could be utilized to identify marginal croplands for CRP enrollment to increase available cover for fawns, while also improving farm profitability for agricultural producers. We also suggest that landowners minimize chemical applications to fallow fields and consider alternative rotations such as natural fallow or planting cover crops to increase concealment cover on the landscape.

Table 2.1 Mean and standard errors of microhabitat characteristics present at bed-sites and random sites for 47 white-tailed fawns (*Odocoileus virginianus*; WTD) and 53 mule deer (*O. hemionus*; MD) fawns between May and August of 2018–2019 in western Kansas, USA.

Microhabitat*	WTD[1]		MD[1]		WTD[0]		MD[0]	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
VOR_0[a,b,c]	8.20	0.09	6.65	0.09	5.32	0.09	4.56	0.07
VOR_{25} [a,b,c]	6.22	0.09	5.30	0.09	3.61	0.09	3.20	0.07
VOR_{50} [a,b,c]	5.20	0.08	4.56	0.08	2.92	0.08	2.58	0.06
VOR_{75} [a,b,c]	4.50	0.08	3.95	0.08	2.53	0.08	2.12	0.06
VOR_{100}[a,b,c]	3.65	0.08	3.23	0.07	2.04	0.07	1.57	0.05
Grass[a,b,c]	54.63	0.83	46.39	0.70	49.33	0.86	53.75	0.71
Forb[b,c]	18.69	0.69	18.30	0.49	12.65	0.50	15.67	0.41
Shrub[a,b,c]	4.43	0.22	7.90	0.39	2.99	0.09	3.11	0.10
Bare[a,b]	6.65	0.29	12.29	0.45	16.44	0.62	12.19	0.48
Litter[a,b]	18.68	0.49	15.63	0.37	21.67	0.61	16.74	0.46
Succulent[a,b,c]	3.20	0.10	4.51	0.15	2.95	0.07	3.86	0.12
Veg_{height} [a,b,c]	70.52	0.82	56.82	0.80	50.21	1.02	44.15	0.70
$Litter_{depth}$ [a,b,c]	1.86	0.07	1.41	0.04	1.23	0.04	1.11	0.03
$Canopy_{Cover}$[a,b,c]	23.09	1.02	3.55	0.42	7.57	0.66	0.94	0.22

[1] Indicates values for actual bed-sites

[0] Indicates values for random available points

[a] Indicates significant difference in bed-sites between species

[b] Indicates significant difference between actual and random points for white-tailed deer fawns

[c] Indicates significant difference between actual and random points for mule deer fawns

*Microhabitat variables measured at bed-sites and available points. VOR, visual obstruction reading (dm); Grass, cover of grass (%); Forb, cover of forb (%); Shrub, cover of shrub (%); Bare, amount of bare ground (%); Litter, cover of litter (%); Succulent, cover of succulent; Veg_{height}, height of tallest vegetation (cm); $Litter_{depth}$, litter depth (cm); and $Canopy_{Cover}$, vegetation canopy cover (%)

Table 2.2 Top microhabitat univariate models using mixed-effect resource selection functions for white-tailed deer (*Odocoileus virginianus*) fawns in western Kansas between May and August 2018–2019. Notes: *We removed models containing parameters with beta values overlapping zero (95% CI), only displayed the top two VOR models and top 5 models overall, and only showed the top ranked representation (i.e., quadratic or linear) for each individual variable (i.e., bare ground, canopy cover, etc.).*

Model[a]	**AIC_c**[b]	**ΔAIC_c**[c]	**w_i**[d]	**K**[e]	**LL**[f]
VOR_{25}	2967.59	0.00	0.99	4	-1479.79
VOR_0	2976.33	8.73	0.01	4	-1484.15
Vegetation Height	3048.64	81.05	0.00	4	-1520.31
Bare Ground	3334.11	366.51	0.00	4	-1663.05
Forest Canopy Cover	3372.13	404.54	0.00	4	-1682.06
Constant	3591.73	624.14	0.00	2	-1793.86

[a] Microhabitat variables. VOR_{25}, 25% visual obstruction; VOR_0, 0% visual obstruction; Vegetation Height, height of tallest vegetation; Bare Ground, amount of bare ground; and Forest Canopy Cover, vegetation canopy cover

[b] Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2002)

[c] Difference in AIC_c relative to minimum AIC

[d] Model weight

[e] Number of parameters (*k=3: linear model, k= 4: quadratic model*)

[f] Log likelihood

Table 2.3 Top microhabitat univariate models using mixed-effect resource selection functions for mule deer (*Odocoileus hemionus*) fawns in western Kansas between May and August 2018–2019. Notes: *We removed models containing parameters with beta values overlapping zero (95% CI), only displayed the top two VOR models, and only showed the top ranked representation (i.e., quadratic or linear) for each individual variable (i.e., bare ground, canopy cover, etc.).*

Model[a]	**AIC_c**[b]	**ΔAIC_c**[c]	w_i[d]	**K**[e]	**LL**[f]
VOR_{75}	3408.23	0.00	0.83	4	-1700.11
VOR_{50}	3411.35	3.12	0.17	4	-1701.67
Vegetation Height	3605.88	197.64	0.00	4	-1798.93
Shrub	3629.14	220.90	0.00	4	-1810.56
Litter Depth	3770.00	361.76	0.00	4	-1880.99
Constant	3871.77	463.53	0.00	2	-1933.88

[a] Microhabitat variables. VOR_{75}, 75% visual obstruction; VOR_{50}, 50% visual obstruction; Vegetation Height, height of tallest vegetation; Shrub, cover of shrubs; and Litter Depth, depth of litter

[b] Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2002)

[c] Difference in AIC_c relative to minimum AIC

[d] Model weight

[e] Number of parameters (*k=3: linear model, k= 4: quadratic model*)

[f] Log likelihood

Table 2.4 Top multivariate bed-site selection models using mixed-effect resource selection functions for white-tailed deer (*Odocoileus virginianus*) fawns in western Kansas between May and August in 2018–2019. *Notes: We removed models containing parameters with beta values including zero (95% CI).*

Model[a]	**AIC_c**[b]	**ΔAIC_c**[c]	**w_i**[d]	**K**[e]	**LL**[f]
VOR_{25} + Bare Ground + Forest Canopy Cover + Grass	2756.73	0.00	0.87	9	-1369.33
VOR_{25} + Bare Ground + Forest Canopy Cover + Forb	2761.08	4.35	0.10	9	-1371.51
VOR_{25} + Bare Ground + Forest Canopy Cover + Shrub	2763.32	6.58	0.03	9	-1372.62
VOR_{25} + Bare Ground + Forest Canopy Cover	2769.42	12.69	0.00	8	-1376.68
VOR_{25} + Forest Canopy Cover + Forb + Grass + Litter	2820.61	63.88	0.00	9	-1401.27
Constant	3591.73	835.00	0.00	2	-1793.86

[a] Microhabitat variables. VOR_{25}, 25% visual obstruction; Bare Ground, amount of bare ground; Forest Canopy Cover, vegetation canopy cover; Grass, cover of grass; Forb, cover of forb; Shrub, cover of shrub; and litter, cover of litter

[b] Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2002)

[c] Difference in AIC_c relative to minimum AIC

[d] Model weight

[e] Number of parameters

[f] Log likelihood

Table 2.5 Top multivariate bed-site selection models using mixed-effect resource selection functions for mule deer (*Odocoileus hemionus*) fawns in western Kansas between May and August in 2018–2019. *Notes: We removed models containing parameters with beta values including zero (95% CI).*

Model[a]	**AIC_c**[b]	**ΔAIC_c**[c]	**w_i**[d]	**K**[e]	**LL**[f]
VOR_{75} + Shrub + Grass + Succulent	3248.71	0.00	1.00	8	-1616.33
VOR_{75} + Shrub + Succulent + Forb	3278.06	29.35	0.00	8	-1631.00
VOR_{75} + Shrub + Succulent	3281.07	32.37	0.00	7	-1633.52
VOR_{75} + Shrub	3291.71	43.01	0.00	6	-1639.84
VOR_{75} + Grass + Forb	3309.33	60.62	0.00	6	-1648.65
Constant	3871.77	623.06	0.00	2	-1933.88

[a] Microhabitat variables. VOR_{75}, 75% visual obstruction; Shrub, cover of shrub; Succulent, cover of succulent; Grass, cover of grass; and Forb, cover of forb

[b] Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2002)

[c] Difference in AIC_c relative to minimum AIC

[d] Model weight

[e] Number of parameters

[f] Log likelihood

Table 2.6 Top land cover bed-site selection models using mixed-effects resource selection functions at the point scale for white-tailed deer (*Odocoileus virginianus*) fawns in western Kansas between May and August of 2018 and 2019.

Model[a]	**AIC_c**[b]	**ΔAIC_c**[c]	**w_i**[d]	**K**[e]	**LL**[f]
Woodland	3423.05	0.00	1.00	3	-1708.52
Cropland	3459.49	36.43	0.00	3	-1726.74
Urban	3578.08	155.02	0.00	3	-1786.03
CRP	3584.61	161.56	0.00	3	-1789.30
Constant	3594.51	171.45	0.00	2	-1795.25
Grassland	3594.79	171.74	0.00	3	-1794.39

[a] Land cover type

[b] Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2002)

[c] Difference in AIC_c relative to minimum AIC

[d] Model weight

[e] Number of parameters

[f] Log likelihood

Table 2.7 Top land cover bed-site selection models using mixed-effects resource selection functions at the point scale for mule deer (*Odocoileus hemionus*) fawns in western Kansas between May and August of 2018 and 2019.

Model[a]	**AIC_c**[b]	**ΔAIC_c**[c]	**w_i**[d]	**K**[e]	**LL**[f]
CRP	3794.29	0.00	1.00	3	-1894.14
Woodland	3820.63	26.34	0.00	3	-1907.31
Crop	3836.21	41.92	0.00	3	-1915.10
Grass	3843.77	49.48	0.00	3	-1918.88
Constant	3860.68	66.39	0.00	2	-1928.34

[a] Land cover variable

[b] Akaike's Information Criterion corrected for small sample size (Burnham and Anderson 2002)

[c] Difference in AIC_c relative to minimum AIC

[d] Model weight

[e] Number of parameters

[f] Log likelihood

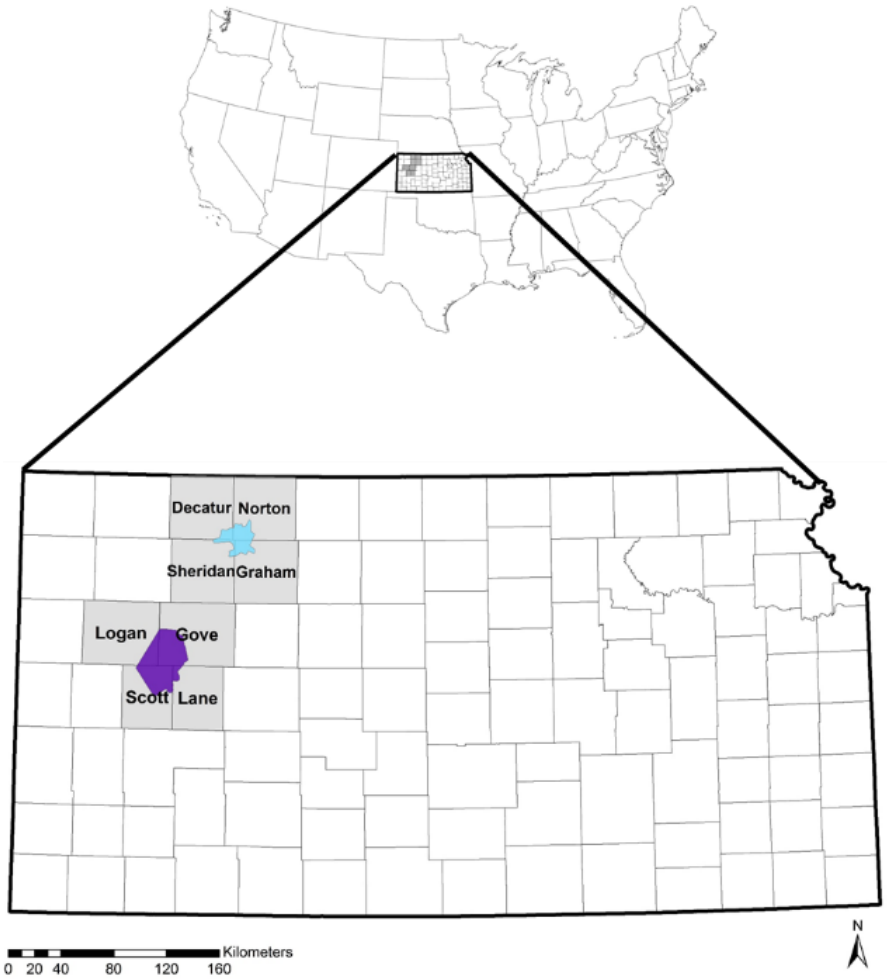

Figure 2.1 North and South fawn study sites (blue and purple, respectively) in Decatur, Norton, Sheridan, Graham, Logan, Gove, Scott, and Lane counties in western Kansas, USA, during the summers of 2018 and 2019.

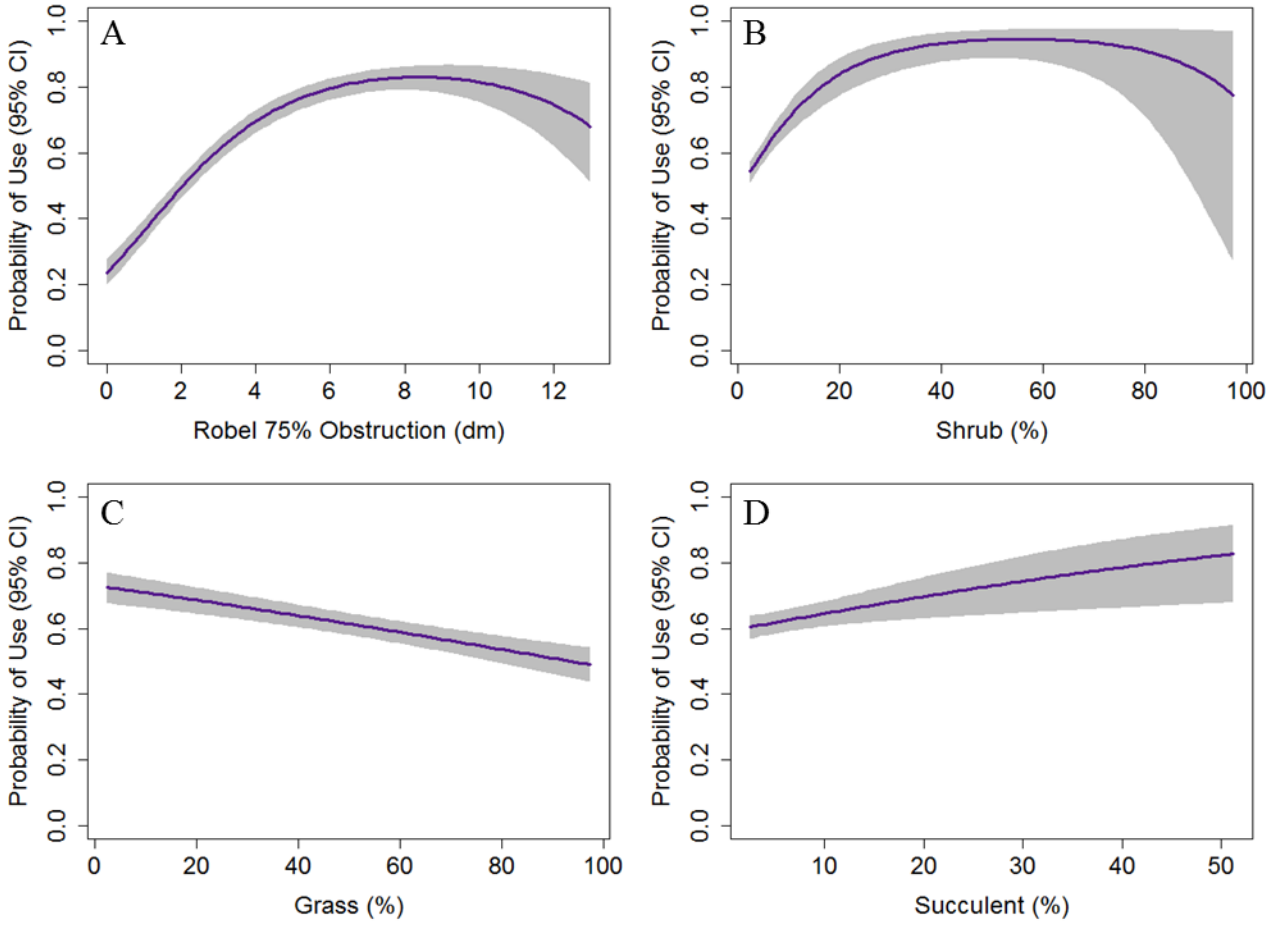

Figure 2.2 Bed-site selection for mule deer (*Odocoileus hemionus*) fawns in western Kansas between May and August of 2018 and 2019. Our top multivariate bed-site selection model shows mule deer bed-sites were best predicted by 75% visual obstruction (A), shrub cover (B), grass cover (C), and succulent cover (D).

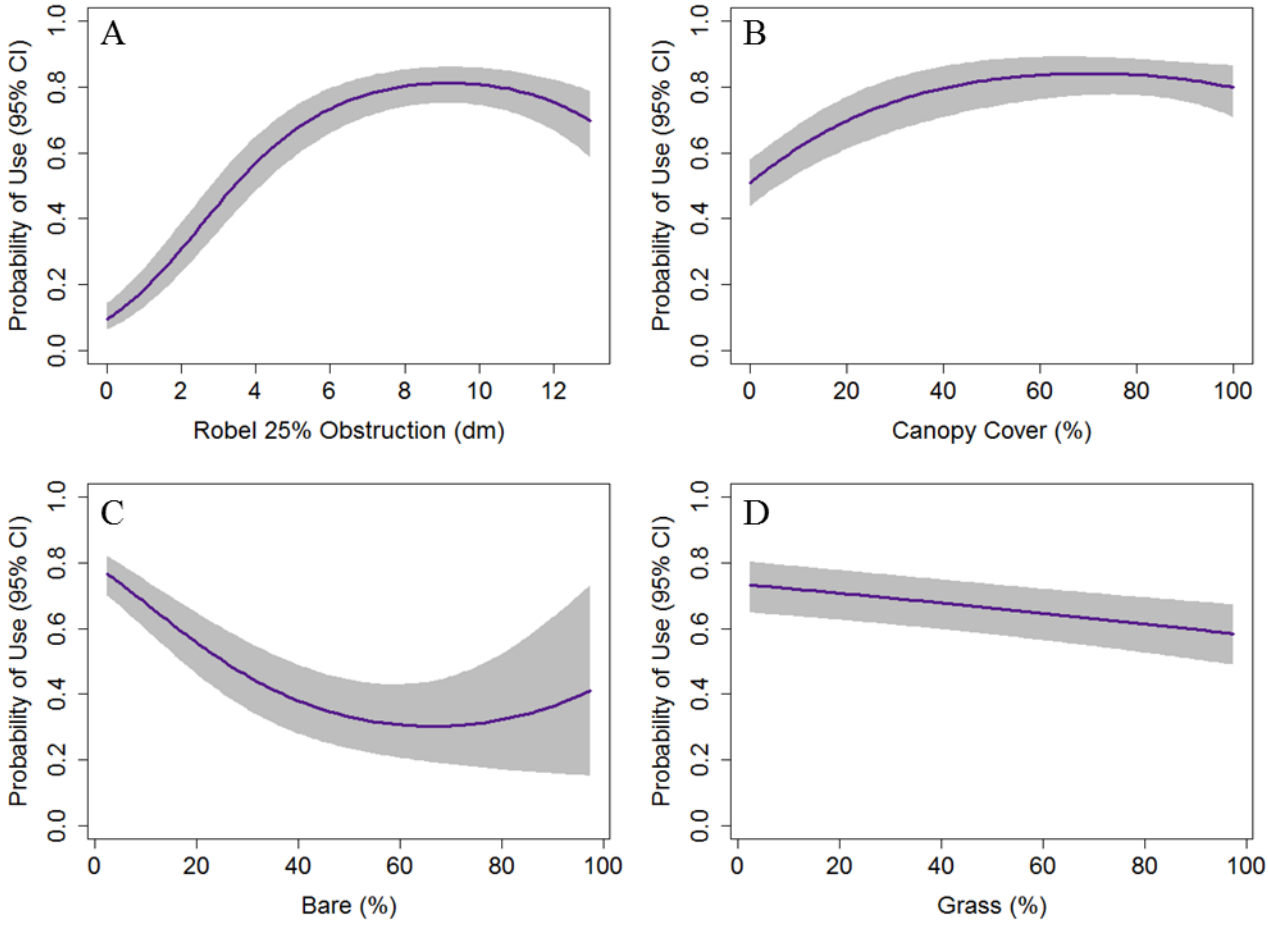

Figure 2.3 Bed-site selection for white-tailed deer (*Odocoileus virginianus*) fawns in western Kansas between May and August of 2018 and 2019. Our top multivariate bed-site selection model shows white-tailed deer bed-sites were best predicted by 25% visual obstruction (A), canopy cover (B), bare ground (C), and grass cover (D).

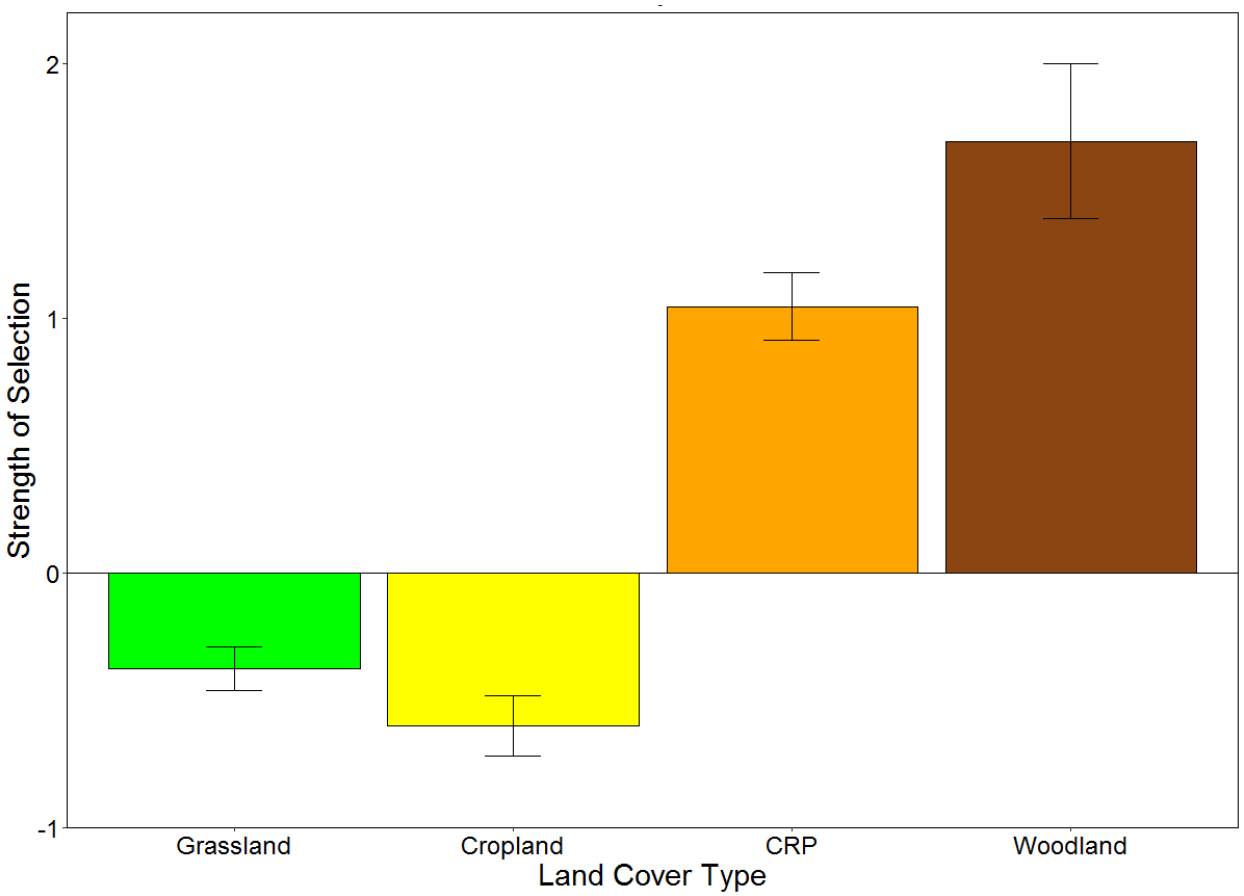

Figure 2.4 Selection strength of land cover types at mule deer (*Odocoileus hemionus*) fawn bed-sites in western Kansas during the summers of 2018–2019.

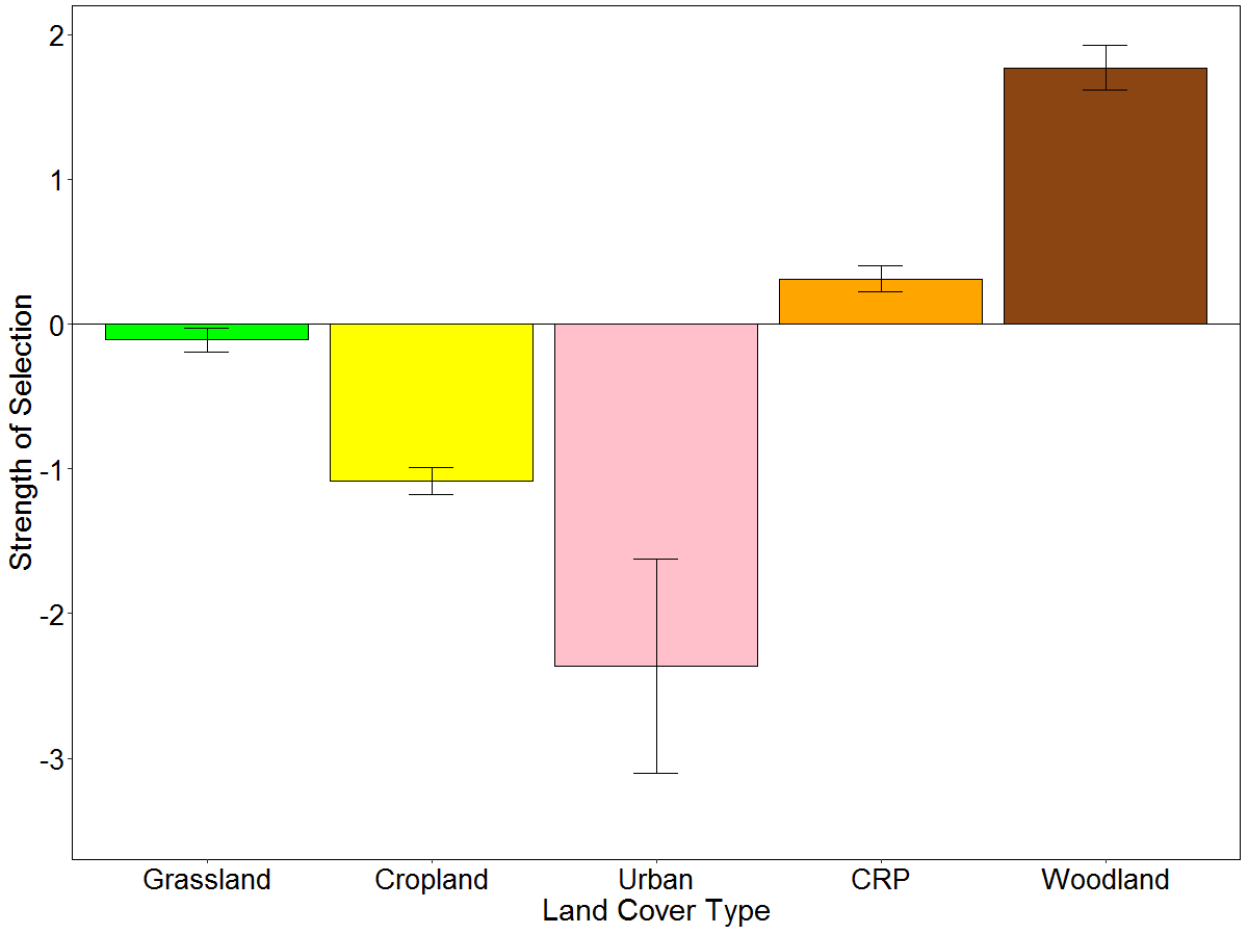

Figure 2.5 Selection strength of land cover types at white-tailed deer (*Odocoileus virginianus*) fawn bed-sites in western Kansas during the summers of 2018–2019.

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Chapter 3 - Survival and cause-specific mortality of mule deer fawns and white-tailed deer fawns in Western Kansas

Abstract

White-tailed deer (*Odocoileus virginianas*) populations have increased and expanded in the Central Plains over the past few decades while mule deer (*O. hemionus*) populations have declined and exhibited westward contraction. The cause for observed dissimilar population trends remains unknown; however, differences in fawn recruitment among species is one proposed hypothesis. We assessed the influence of fawn intrinsic factors, maternal condition, and bed-site habitat characteristics on fawn survival of mule deer and white-tailed deer fawns to test the hypothesis that fawn survival differs between species and survival within each species may be driven by different factors. We captured 120 does (30 white-tailed deer, 30 mule deer; annually) during February 2018 and 2019 utilizing helicopter capture techniques. All pregnant does were fitted with GPS collars and received vaginal implant transmitters. We captured 100 fawns during 12 May - 25 June 2018 and 2019 in western Kansas, fitted them with expandable VHF collars, and visually located fawns daily to assess survival. Overall 10-week fawn survival was 0.32 and did not differ by study area ($p = 0.34$), species ($p = 0.41$), or sex ($p = 0.90$). Chest girth of adult does was the best intrinsic predictor of 10-week survival for white-tailed deer fawns and larger does increased fawn survival. Fawn and maternal intrinsic factors did not explain 10-week survival for mule deer fawns. Mule deer fawn home ranges containing grasslands had greater survival, whereas white-tailed deer fawn survival decreased as woodland cover within the home range increased. Mule deer fawn survival also increased with landscape shape index revealing edge and disaggregation benefits to survival. Our research suggests

landscape composition and configuration could influence deer population trends in Kansas. Managers should focus on creating heterogeneous landscapes composed mainly of native grasslands with patches of CRP distributed throughout to bolster mule deer fawn survival.

Introduction

White-tailed deer (*Odocoileus virginianus*; hereafter 'WTD') and mule deer (*O. hemionus*; hereafter MD) are sympatric in the Great Plains of North America but have dissimilar spatiotemporal population and distribution trends. White-tailed deer populations are increasing and expanding (Martinka 1968, Van der Hoek et al. 2002) while MD populations are decreasing and contracting westward (Ballard et al. 2001, Shallow et al. 2015). Multiple independent surveys conducted by Kansas Department of Wildlife, Parks and Tourism (spotlight, hunter-harvest, and hunter-observation surveys) suggest these trends are similar in Kansas, where both species overlap in distribution and MD occur at the eastern edge of their geographic range.

Although the underlying cause for dissimilar population trends among MD and WTD remains unclear, low MD fawn recruitment may be a plausible explanation (Dietz and Nagy 1976, Hamlin et al. 1984, Pojar and Bowden 2004, Lomas and Bender 2007). Relatively variable juvenile survival rates, compared to more stable adult survival rates, can drive species-specific population dynamics (Lomas and Bender 2007). Reported WTD fawn survival rates are highly variable throughout the United States, ranging from 0.14 – 0.90 (Burroughs et al. 2006, Rohm et al. 2007, Grovenburg et al. 2011, Chitwood et al. 2015, Shuman et al. 2017, Warbington et al. 2017) where lower survival rates were common in the southeastern United States (Gingerly et al. 2018). Most MD fawn survival rates vary across the range of the species (0.30 – 0.78; Pojar and

Bowden 2004, Johnston-Yellin et al. 2009, Shallow et al. 2015); however, MD fawn survival rates as low as 0.00 have been recorded in New Mexico during drought conditions (Lomas and Bender 2007).

Several factors contribute to fawn survival including intrinsic factors (eg. birth mass, sex; Johnstone-Yellin et al. 2009, Shuman et al. 2017) and maternal health (eg. doe mass, body length, body condition; Shallow et al. 2015). Landscape configuration and composition (eg. percent cropland, grassland, edge) can also influence survival of WTD fawns (Gingerly et al. 2018). Although the influence of microhabitat characteristics at the bed-site (eg. vegetative structure, percent grass, percent forb) on fawn survival are largely unknown for WTD and MD, they are important predictors of survival in roe deer (*Capreolus capreolus*) fawns and can provide thermal cover and concealment from predators (Moorter et al. 2009).

To our knowledge, no study has simultaneously estimated fawn survival rates in two sympatric deer species in Kansas. Our objectives were to quantify fawn survival, determine cause-specific mortality of WTD and MD fawns, and examine the evidence for these factors as drivers of dissimilar population abundances between species. We assessed effects of fawn intrinsic factors, maternal condition, and both microhabitat and macrohabitat characteristics at fawn bed-sites on 10-week fawn survival. Based on previous research of deer populations in the United States, we predicted 1) lower survival rates in MD fawns compared to WTD fawns, 2) a positive association between doe body condition, a surrogate for fawn condition, and fawn survival, 3) greater vegetative structure at fawn bed-sites would result in greater fawn survival rates, and 4) predation would be the leading cause of fawn mortality.

Study Area

We conducted this study at two sites composed mostly of privately owned land in Western Kansas (Figure 3.1). The North site (~85,000 ha) occurred in Graham, Norton, Sheridan, and Decatur counties, about 148 km away from the South site (~137,000 ha), which was located in Logan, Scott, Gove, and Lane counties. Both sites were located in the Central Great Plains and High Plains level III ecoregions (U.S. Environmental Protection Agency). Summer (May-August) temperatures at the North site ranged from 6.7–40.6 ˚C and -1.0–42.2 ˚C with 598.0 mm and 584.5 mm total summer precipitation in 2018 and 2019, respectively (Hill City Municipal Airport, KS, US, National Oceanic and Atmospheric Administration [NOAA], 2019). Summer temperatures at the South site ranged from 3.9–39.4 ˚C and -1.7–39.4 ˚C with 427.8 mm and 315.8 mm total summer precipitation in 2018 and 2019, respectively (Scott City, KS, USA, NOAA, 2019). We experienced abnormally wet summers during our study compared to the previous 20 years when total summer precipitation averaged 288.80 mm ± 100.58 and 275.84 mm ± 81.79 per year for the North and South study site, respectively.

Agricultural lands composed of grazed grassland and cultivated cropland dominated both study sites. The North site consisted of 53.3% cropland, 37.6% grassland, 6.2% Conservation Reserve Program (CRP), 2.3% woodlands, and 0.6% urban and the South site contained 45.3% cropland, 45.1% grassland, 7.7% CRP, 1.2% woodland, and 0.7% urban. The South site contained more ravines and greater elevation variation, whereas the North site had lower elevation and a riparian area.

Row-crop agriculture consisted of corn (*Zea mays*), wheat (*Triticum aestivum*), and milo (*Sorghum bicolor*) at both sites. Additionally, the North site contained soybeans (*Glycine max*) and alfalfa (*Medicago sativa*). Grasslands consisted of native mixed-grass prairie primarily

grazed by cattle, while CRP lands consisted of un-grazed tallgrass prairie species including big bluestem (*Andropogon gerardi*), switchgrass (*Panicum virgatum*), and Indiangrass (*Sorghastrum nutans*). Common grasses included little bluestem (*Schizachyrium scoparium*), buffalo grass (*Bouteloua dactyloides*), and blue grama (*Bouteloua gracilis*). Broom snakeweed (*Gutierrezia sarothrae*), common mullein (*Verbascum thapsus*) and tall thistle (*Cirsium altissimum*) were typical forbs, and prevalent succulents included yucca (*Yucca glauca*) and prickly pear cactus (*Opuntia macrorhiza*). Common tree species included American elm (*Ulmus americana*), hackberry (*Celtis occidentalis*.), black cherry (*Prunus serotina*), eastern cottonwood (*Populus deltoids*), honey locust (*Gleditsia triacanthos*), black walnut (*Juglans nigra*), mulberry (*Morus rubra*) and eastern red cedar (*Juniperus virginiana*). Plum thickets (*Prunus* angustifolia) and smooth sumac (*Rhus glabra*) were frequent shrubs in western Kansas.

Methods

Adult Capture

We captured 120 adult does (30 WTD, 30 MD; annually) between two study sites in February 2018 and February 2019 using helicopter-capture techniques. Helicopter-capture techniques allow for quicker acquisition of animals and are relatively safe compared to other capture methods (Webb et al. 2007). At each site, the helicopter crew entangled deer using a net gun, administered light sedation (15 mg Butorphanol [50mg/ml], 15 mg Azaperone [50mg/ml], and 15 mg Midazolam [50mg/ml]), and transported deer to a central location (≤ 5km from capture location) for processing. All capture procedures were approved by the Kansas State University (KSU) Institution Animal Care and Use Committee (protocol 3963), were compliant

with American Society of Mammologist standards for field studies (Sikes et al. 2016), and authorized under the state of Kansas scientific, education, or exhibition wildlife permits (SC-024-2018, SC-015-2019).

Does were fitted with 731g VERTEX Plus GPS collars (Vectronic Aerospace GmbH, Berlin, Germany) programmed to obtain hourly GPS locations. We also recorded morphological measurements of does to assess maternal condition at capture (Table 3.1). We performed ultrasound screenings (IBEX PRO/r, E.I. Medical Imaging, Loveland, CO) to assess pregnancy status and estimate loin and rump fat reserves (Cook et al. 2001). Pregnant deer received a 30g vaginal implant transmitter (VIT; Vectronic Aerospace GmbH, Berlin, Germany) that synchronized to Vertex Plus GPS collars via Ultra High Frequency (UHF). VITs switched into mortality mode if the sensor failed to record activity over a 5-minute period, or registered a temperature ≤34˚C for 50 min. If a VIT parturition or adult mortality event occurred, Vectronic sent an email and text notification to project personnel. Processing time of captured does was short ($\bar{x}$= 13 minutes) and we released all deer at one or two central processing locations within each study site.

Fawn Capture

All fawn births occurred between 12 May – 25 June during summer 2018 and 2019. We waited three hours after receiving a VIT parturition notification before locating an associated birth site to allow time for the doe to clean and bond with the fawn. After locating the expelled VIT, we spent ≤2 hours searching for fawns. We processed fawns 15-20 m away from the bed-site to reduce disturbance to vegetation and wore nitrile gloves to minimize scent transfer. In 2019, project personal also wore rubber boots to limit scent transfer. We identified sex and

species, and fitted fawns with a 56-g expandable VHF collar (Vectronic Aerospace GmbH, Berlin, Germany). We also affixed one plastic button ear tag (Button Combo, Y-TEX, Cody, WY) and one metal ear tag (Style 505, National Band & Tag Company, Newport, KY) to each fawn and measured intrinsic features (birth mass, body length, hind foot length, and front hoof growth; Table 3.2). We handled fawns quickly ($\bar{x}$ =10 minutes) to limit stress on both fawns and does.

Fawn Monitoring and Mortality Assessment

We monitored daily survival and bed-site selection of individual fawns up to 10 weeks after capture. We used VHF homing to locate individuals, recorded the location of the bed-site with a handheld GPS unit (Map 64st, Garmin, Olathe, KS), and returned the following day to measure microhabitat characteristics at the bed-site (Table 3.3; Chapter 2). We also recorded microhabitat characteristics at a random point 300 m away from each bed-site, and used functions in the base packages in R version 3.5 (R Core Team 2019) to generate these random points. We measured tree canopy cover with a convex densiometer (Lemmon 1956; Forestry Suppliers, Inc, Jackson , MS), herbaceous canopy cover of six plant functional groups (grass, forb, shrub, bare, succulent, and litter) with a 25 x 50-cm Daubenmire frame (Daubenmire 1959), and visual obstruction with a 13-dm Robel pole (Robel et al. 1970) using a modified approach. Our modified visual obstruction approach included measurements of 0, 25, 50, and 75 percent visual obstruction in addition to the standard 100 percent visual obstruction. Additionally, within each Daubenmire frame, we recorded litter depth (in the upper right corner) and height of the tallest vegetation. At each habitat assessment point, we estimated four tree canopy cover, four

visual obstruction, and eight herbaceous canopy cover readings. We recorded one tree canopy cover, one visual obstruction, and one herbaceous canopy cover reading in each cardinal direction, 4 m from the bed-site. We took an additional herbaceous canopy cover reading in each cardinal direction adjacent to the center of the bed-site.

We investigated all mortality signals within 24 hours in 2018 and within 12 hours in 2019. We documented mortality causes as natural (unscathed intact carcasses), predation (bite wounds and hemorrhaging present), anthropogenic (found in recently harvested fields or roads), or unknown. We assigned an 'unknown' mortality cause if there was little evidence to suggest one of the above-described categories or if we could not distinguish predation from scavenging. For suspected predation mortalities during the first year of our study, we swabbed the immediate area around bite wounds for saliva with a cotton tip applicator. Applicator samples (n = 15) were stored in coin envelopes at room temperature and then sent to Wildlife Genetics International (Nelson, Canada) for predator identification using species-specific DNA identification methods. In 2019, intact deceased fawns (n = 5) were stored on ice and transported to a laboratory for necropsy (Kansas State Veterinary Diagnostic Laboratory, Manhattan, KS).

Analyses

All statistical analyses were conducted in R (version 3.5.0., R Core Team 2019). We used analysis of variance (ANOVA) to determine if fawn intrinsic factors differed among species, sex, or sites at the 95% confidence level and modeled fawn survival using known-fate models in the survival package (survival; v. 2.44-1.1; Therneau 2015). Fawn age was classified in days and we estimated 70-day fawn survival with Kaplan-Meier models using a non-staggered entry approach (Pojar and Bowden 2004). Fawns were right censored when there was no evidence of a mortality

event (i.e., slipped collar or collar failure), along with fawns that survived the 70-day extent of the study.

We used Cox proportional hazards models to assess effects of fawn intrinsic factors, adult maternal conditions, and study site on fawn survival. We assessed 7-day fawn survival in addition to 70-day survival due to greater fawn mortality within the first week of life. To assess fawn survival, we created a single model set for each species of deer including parameters we expected to be biologically important to fawns. Model sets contained 15 univariate models. We identified three correlated ($|r| \geq 0.60$) fawn intrinsic and maternal condition variables for MD and five correlated variables for WTD. We used Akaike's Information Criterion adjusted for small sample sizes (AICc) to assess support for models in each candidate set (package AICcmodavg; Mazerolle 2019) and considered models ≤ 2.00 AICc to be competitive (Burnham and Anderson 2002). We used Akaike weights (w_i) to further assess competing models and removed models from consideration *post hoc* if the standard error of parameter estimates overlapped zero for any covariate in that specific model.

Previous studies estimated fawn home ranges via fixed kernel methods (Grovenburg et al. 2012, Vreeland et al. 2004). However, these studies were unable to estimate home ranges for all individuals because early mortality and censor events resulted in insufficient fawn locations to use fixed kernel methods. Due to insufficient fawn locations, studies have alternatively constructed buffers of subjective sizes around fawn capture sites as a proxy of fawn home ranges. Buffer sizes included year- and site-specific median home ranges in Pennsylvania (Vreeland et al. 2004), 3 separate monthly home ranges in Illinois (Rohm et al. 2007), and year-specific 30-day mean fawn home ranges in South Dakota (Grovenburg et al. 2012). We created kernel density estimates (KDE) for all fawns that had sufficient locations (i.e. ≥30 locations), but

we were unable to calculate KDEs for 60% of our fawns due to early mortality or censoring events. To avoid creating arbitrary buffers for fawns with ≤30 locations, we explored an alternative process. We calculated 50-95% (5% step) biased-random bridges (BRB) isopleths using movement data from associated maternal does. BRB isopleths were compared to constructed KDEs to determine the BRB isopleth that best approximated the KDE for each fawn species. We created all KDE and BRB home ranges using package "adehabitatHR" in R (Calenge 2006).

We concluded that 85% and 95% BRB isopleths represented KDE home ranges of WTD fawns and MD fawns, respectively. At the macrohabitat scale, we created a ground-truthed map in a geographic information system (GIS; ArcMap 10.6, Esri, Redlands, CA) for both study sites and classified land cover into five categories (grassland, cropland, urban, Conservation Reserve Program [CRP], and woodlands). Landscape information from our map was extracted to each individual BRB fawn home range and we used Fragstats (v. 4.2.1; McGarigal et al.) to calculate the percent land cover composition and values of eight landscape metrics (largest patch index, edge density, landscape shape index, mean perimeter-area ratio, perimeter-area fractal dimension, interspersion juxtaposition index, patch richness, and Simpson's diversity index).

We assessed the influence of habitat variables on fawn survival at the macrohabitat and microhabitat scale. For macrohabitat analyses, we used landscape composition and configuration calculated within each BRB home range as covariates in Cox proportional hazards models. The macrohabitat model suite consisted of six land cover composition models and nine landscape configuration models. We ranked models for each species separately using AICc and considered any models within 2 AICc to be competitive. At the microhabitat scale, we used Tukey HSD

tests to determine if bed-site characteristics within each species differed between fawns that survived the 70-day study period compared to fawns that died prior to 70 days.

Results

We captured 53 MD fawns and 47 WTD fawns during 12 May – 25 June 2018, 2019 (n = 100). We captured 48 fawns at the North site (MD: 22, WTD: 26; hereafter 'N') and 52 fawns in the South site (MD 31, WTD 21; hereafter 'S'). We successfully caught fawns from 53.3% (n = 64) of all deployed Vaginal Implant Transmitters (VIT; n = 120). Failure to capture VIT-associated fawns was due to VIT malfunctions (23.3%, n = 28), unsuccessful searches (10.0%, n = 12), doe mortalities before fawning season (5.0%, n = 6), restricted land access (3.3%, n = 4), premature expulsion events (3.3%, n = 4), and VITs that were never expelled (1.7%, n = 2). Median parturition date for all fawns was 28 May and did not differ by year. Mean birth mass of fawns caught ≤2 days old (n = 93) was 3.41 ± 0.06 kg and was similar between sexes (p = 0.10), sites (p = 0.32), and years (p = 0.20; Table 3.2). However, MD fawns were 8% heavier than WTD fawns with averages of 3.55 kg and 3.28 kg respectively (p = 0.04; Table 3.2).

Overall 10-week survival was 0.32 ± 0.05 (Figure 3.2) and did not differ by study site (N: 0.39 ± 0.19, S: 0.23 ± 0.31, p = 0.34, Figure 3.3), species (MD: 0.25 ± 0.07, WTD: 0.41 ± 0.08, p = 0.46, Figure 3.4) or sex (M: 0.29 ± 0.07, F: 0.36 ± 0.08, p = 0.90). Mean collar exit date was 30.98 days after capture and included known mortalities, collars located in the field without a carcass present (possible mortality or slipped collar), or a collar signal was lost. Mean exit date was similar among species (MD: 30.91 ± 3.34, WTD: 31.06 ± 3.95, p = 0.98) but differed by study site (N: 36.38 ± 3.91, S: 26.00 ± 3.22, p = 0.04).

The majority of collared fawns resulted in mortality (n = 60; 60%). We censored incidents related to slipped collars (n = 16; 16%) and collar malfunctions (n = 3; 3%). Mule deer fawn mortalities were due to unknown (n = 14; 40%), predation (n = 12; 34%), natural (n = 8; 23%), and agriculture (n = 1; 3%) causes. WTD fawn mortalities included predation (n = 10; 40%), unknown (n = 9; 36%), natural (n = 5; 20%), and agriculture (n = 1; 4%). We observed predation (n = 11; 39%), unknown (n = 11; 39%), natural (n = 5; 18%), and agriculture (n = 1; 4%) mortalities in the North site and unknown (n = 12; 38%), predation (n = 11; 37%), natural (n = 8; 25%), and agriculture (n = 1; 3%) mortalities in the South site (Table 3.3). Predatory DNA sampling in 2018 revealed coyote DNA was present at 8 (53%) of 15 suspected predation mortalities and 7 (47%) samples failed to yield predatory species identification. In 2019, KSU laboratory results concluded that mortalities of intact fawns resulted from malnutrition (n = 3 WTD; 60%), bacterial infection (n =1 MD; 20%), and predation (n =1 WTD; 20%).

Our top univariate Cox proportional hazards model for intrinsic factors of WTD fawns indicated adult chest girth was associated with lower mortality risk (β = -0.10, SE = 0.05), and therefore, positively associated with 70-day fawn survival (Table 3.4). Fawn birth mass carried almost all of the model weight (w_i = 0.99); however, hazard confidence intervals overlapped 1, which is equivalent to standard beta coefficients including 0, and resulted in the dismissal of this model. Adult body condition, adult loin, fawn body, and adult body confidence intervals also overlapped 1 and were removed from consideration. Fawn body length was negatively associated with mortality risk (β = -0.14, SE = 0.05), positively influenced WTD fawn 7-day survival, and was the top model after removing other models because of model uncertainty.

Adult and fawn intrinsic Cox proportional hazards models failed to explain 70-day survival of mule deer fawns. Fawn birth mass was positively related to survival in MD fawns,

carried all model weight (w_i = 1.0, Table 3.5), but was removed from the model set due to hazard confidence intervals overlapping 1. Similarly, high model uncertainty removed all 70-day MD fawn survival models that ranked higher than the null model from consideration. Male MD fawns had higher 7-day fawn survival than females (β = -1.36, SE = 0.68) and sex was the top ranking model after removing models due to model uncertainty.

Bed-sites of WTD fawns that survived 70 days (n = 11) had less bare ground cover (lived: 6.11 ± 0.35, died: 8.92 ± 0.79; $p < 0.01$), shrub cover (lived: 3.46 ± 0.16 died: 4.40 ± 0.49; $p = 0.02$) and visual obstruction (0%, lived: 8.26 ± 0.11, died: 8.73 ± 0.17, $p = 0.02$; 50%, lived: 5.00 ± 0.10, died: 5.64 ± 0.18, $p < 0.01$; 75%, lived: 4.22 ± 0.09, died: 5.01 ± 0.17, $p < 0.01$; 100%, lived: 3.34 ± 0.09, died: 4.16 ± 0.17; $p < 0.01$) than bed-sites of WTD fawns that died (Figure 3.5, 3.7). Visual obstruction (25%, $p = 0.09$), litter depth ($p = 0.59$), tree canopy cover ($p = 0.20$) and canopy cover of grass ($p = 0.09$), forb (p = 0.35), litter ($p = 0.31$), and succulent ($p = 0.08$) at WTD fawn bed-sites did not differ between fates.

Surviving MD fawns (n = 9) had bed-sites with greater visual obstruction (0%, lived: 7.56 ± 0.14, died: 5.95 ± 0.13; 25%, lived: 6.21 ± 0.14, died: 4.63 ± 0.13; 50%, lived: 5.43 ± 0.14, died: 3.95 ± 0.12; 75%, lived: 4.71 ± 0.13, died: 3.42 ± 0.11; 100%, lived: 3.87 ± 0.12, died: 2.75 ± 0.11; $p < 0.01$), deeper litter depth (lived: 1.44 ± 0.05, died: 1.19 ± 0.05 $p < 0.01$), and greater cover of grass (lived: 48.30 ± 1.09, died: 44.20 ± 1.06; $p < 0.01$), forbs (lived: 21.93 ± 0.88, died: 13.40 ± 0.52; $p < 0.01$), and tree canopy cover (5.54 ± 0.80, died: 2.78 ± 0.59; $p < 0.01$) but less cover of succulent (lived: 4.13 ± 0..21, died: 5.03 ± 0.27; $p < 0.01$), litter (lived: 14.52 ± 0.49, died: 16.64 ± 0.61; $p < 0.01$), and bare ground (lived: 8.50 ± 0.54, died: 16.72 ± 0.82; $p < 0.01$) compared to bed-sites of deceased MD fawns (Figure 3.6, 3.7). Ground cover of shrub ($p = 0.18$) at bed-sites did not differ between fates

Macrohabitat characteristics also explained variation in fawn survival in western Kansas. Percent composition of grassland within a fawn's home range was the best explanatory variable of MD fawn survival in our macrohabitat Cox proportional hazards model suite (Table 3.6). Our top ranked model was a quadratic representation of grassland within the home range, contained 43% of model weight, and was negatively associated with hazard (β = -0.099, SE = 0.030). CRP (β = -0.081, SE = 0.038) and CRP^2 (β = -0.173, SE = 0.085) were competitive models for MD fawn survival, but were dismissed due to hazard confidence interval overlapping 1. Composition of woodland in a fawn's home range best explained WTD fawn survival (Table 3.7). Fawn survival declined as percent woodland within the home range increased because hazard increased (β = 0.037, SE = 0.010). Our land cover composition model suite revealed landscape shape index (β = -0.893, SE = 0.292) best explained MD fawn hazard ratio (Table 3.8), suggesting fawn survival increased with edge and disaggregation. Mean perimeter-area ratio (β = 0.002, SE = 0.001) outcompeted the constant model for the top land cover configuration model explaining white-tailed fawn survival; however, the hazard confidence intervals overlapped one and we removed this model from consideration (Table 3.9).

Discussion

Maternal characteristics (i.e., body condition and age) affect fawn intrinsic variables (i.e., sex, birth mass, fawn body length), which may influence fawn survival, and are important for understanding population dynamics (Carstensen et al. 2009, Grovenburg et al. 2012, Shuman et al. 2017). We discovered adult chest girth had a positive relationship with WTD fawn survival. Adult chest measurements were correlated with adult mass (r = 0.67), implying larger chest measurements were indicative of heavier does. Heavier does could represent larger, more

dominant individuals, in prime reproductive age with greater nutritional reserves. Mean WTD doe age ($\overline{x}$ = 3.57 ± 0.14 years, range: 2.50 – 6.00) suggested maternal does likely had prior experience raising fawns, but were young enough to be in prime physical condition. Poor body condition of dams is linked to lower fawn survival in cervids explaining why larger adult morphometrics increased fawn survival rates in Kansas (Shallow et al. 2015).

We noticed discrepancies in top intrinsic models explaining variation in 70-day fawn survival vs 7-day fawn survival – the period when fawns are most susceptible to mortality. Adult chest girth best predicted 10-week WTD fawn survival; however, fawn body length best described 7-day WTD fawn survival. Fawn body length positively influenced WTD fawn survival, and was correlated with fawn birth mass (r = 0.80), which has been shown to increase fawn survival, likely because of increased growth rates and maternal does in better condition (Lomas and Bender 2007, Shuman et al. 2017). We did not detect an effect of sex on 10-week fawn survival similar to research in Pennsylvania (Vreeland et al. 2004) and Michigan (Kautz et al. 2019), but male MD fawns had greater survival compared to female MD fawns during the first week of life. While male WTD fawns had greater survival than females fawns in Louisiana (Shuman et al. 2017), other studies documented lower fawn survival in males and suggested increased activity patterns in males left them more susceptible to predation (Warbington et al. 2007, Carstensen et al. 2009). It is likely we did not observe these latter trends because fawns exhibit sedentary behavior during the first two weeks of life (Rohm et al. 2007) and we assessed fawn survival up to 7 days compared to 12-weeks (Carstensen et al. 2009) and 110-days (Warbington et al. 2017). Increased male MD fawn survival during the first week of life in Kansas, was likely a result of greater birth mass of males than females (Male: 3.68 kg ± 0.08, Female: 3.40 kg ± 0.10). Maternal conditions influence fawn growth and fawns are capable of

gaining 0.31 kg/day after birth (Nelson and Woolf 1985, Sams et al. 1996). Variation between initial fawn capture measurements is likely greater in the first few days of life and may have a greater affect on short-term fawn survival before fawns have time to grow. This likely explains why fawn characteristics were better predicators of 7-day survival and adult morphometrics explained fawn survival over a broader period (10-week).

Predation is the most common reported cause of mortality in fawns (Shuman et al. 2017, Vreeland et al. 2004, Rohm et al. 2007, Nelson and Woolf 1987, Pojar and Bowden 2004, Carstensen et al. 2009) and was the top cause of fawn mortality in this study. In fact, true predation rates are probably greater in Kansas than our reported values because it is likely that many of our unknown mortality events were predations. Coyote DNA was present at the majority (56%) of suspected fawn mortalities in 2018. This suggests coyotes played a predominant role in fawn mortalities in Kansas similar to results from the Northern Great Plains (Grovenburg et al. 2012); however, 47% of our samples failed to yield predatory ID and it is possible some DNA was associated with scavenging. Warbington et al. (2017) reported predation as the leading cause of mortality at one study site, but showed natural deaths as the leading cause of mortality at another site. Although we did not see a change in hierarchical ranking between predation and natural mortalities events, composition of mortality types between the two fawn species and two study sites differed. Mule deer fawns had less predation and more natural deaths, compared to WTD fawns, and fawns in the North site had more predation and fewer natural deaths than the South site. This suggests that MD fawns at the South site were most susceptible to natural deaths. It is likely that wet summers in western Kansas during 2018 and 2019 contributed to natural fawn deaths as cool and damp weather conditions can lead to complications with exposure through thermal instability (Pojar and Bowden 2004).

Microhabitat characteristics differed between fawns that survived the 70-day study period compared to those that died. The majority of differences in vegetative composition between the two fawn fates were small and likely not biologically relevant. However, we believe differences between fawn fates related to forb and bare ground cover at MD fawn bed-sites, and vegetative structure at bed-sites of both species were large enough to influence fawn survival. Forbs provided dense herbaceous cover in western Kansas capable of concealing fawns and likely increased fawn survival by decreasing detectability by predators. Forbs comprised the majority (54%) of contents from sampled MD rumens during the beginning of summer in Montana (Dusek 1975), and may be associated with increased nutritional demands of maternal does to produce milk for fawns (Tollefson et al. 2010). Fawns <8 weeks of age rely on cryptic coloration and static movement to avoid predation (Nelson and Woolf 1987). Vegetation structure can increase survival (Grovenburg et al. 2012) by providing concealment and thermal cover, which may explain why we measured greater vegetative structure and less percent bare ground at surviving MD bed-sites. Surprisingly, we saw less vegetative structure at surviving WTD fawn bed-sites compared to fawns that died, suggesting WTD may not utilize vegetative structure as much as MD fawns as they age. Our WTD vegetative structure results were dissimilar to those from South Dakota (Grovenburg et al. 2012), where fawn survival increased with vegetative cover, and South Carolina (Kilgo et al. 2014) where understory vegetation had little effect on fawn survival. It is likely our results differed from South Dakota and South Carolina because we measured vegetation cover at a much smaller scale, compared vegetation between fawn fates rather than daily or weekly survival, and our prairie ecosystem differs from the forested regions of South Carolina.

We found that land cover composition within a fawn's home range influenced survival in western Kansas. Survival of WTD fawns decreased as the percent composition of woodlands in fawn home ranges increased. Grovenburg et al. (2012) presented comparable results from South Dakota in WTD fawns and suggested small patches of trees provided minimal cover and were easier for predators to search efficiently. Similarly, in Louisiana, Shuman et al. (2017) suggested proximity to young reforestation might decrease survival due to increased predation risk. Conversely, in Illinois, survival was greater in WTD fawns residing in large forest patches adjacent to multiple smaller non-forested patches (Rohm et al. 2007). Woodlands in western Kansas were composed mainly of linear shelterbelts or narrow patches along a riparian zone similar to those in South Dakota, rather than the large forest patches observed in Illinois. Limited woodlands in parts of Kansas may act as ecological traps by providing inadequate concealment cover and allowing easier access for predators.

Mule deer are a grassland species in the Great Plains, so we expected fawn survival to increase with greater grassland composition in the home range. We showed grassland composition within fawn home ranges best explained MD fawn survival, demonstrating the importance of historical native mixed-grass prairie in Kansas. Mule deer fawn survival increased until grassland composition within the home range reached ~42%; at which point, fawn survival began to decline. This quadratic relationship suggests that intact native grasslands are still important for this species, but that reduced cover in western Kansas rangelands because of overgrazing is limiting fawn survival. Moreover, land cover heterogeneity in our study areas likely provided concealment cover for fawns and could also result in reduced travel times between resources (Rohm et al. 2007) or reduced predation by coyotes (Gulsby et al. 2017). Median grassland composition of MD fawn home ranges was 90.60% ($\overline{x}$ = 78.25 ± 3.75), well

above the reported 42% threshold, possibly explaining lower MD fawn survival rates. Large grassland composition within MD fawn home ranges also bolsters the importance of managing rangelands to promote heterogeneity in vegetation density and height, capable of providing cover for bedded fawns.

Landscape Shape Index was the top land cover configuration model for explaining MD fawn survival. Land cover configuration did not explain WTD fawn survival. Mule deer fawn survival increased as patch boundaries became irregular and disaggregated, therefore containing more land cover heterogeneity and edge within the home range. Landscape heterogeneity can alter species interactions and population persistence (Fahrig 2011). Predation risk of WTD fawns increased as edge and land cover heterogeneity in the home range decreased in South Carolina (Gulsby et al. 2017). Similarly, in Illinois, areas with high WTD fawn survival contained greater edge and large irregular forest patches that potentially inhibited coyote predation efficiency (Rohm et al. 2007). Mixed-grass prairie and shortgrass prairie have both declined, 18.3% and 7.7%, respectively, in Kansas from 1973 to 1993 with the majority of lost prairie converted to cropland increasing landscape heterogeneity (Peterson 2004). Although land cover configuration did not explain WTD fawn survival, agriculture lands increased WTD fawn survival across North America compared to landscapes comprised of homogenous forests (Gingerly 2018), bolstering the conclusion that landscape heterogeneity is beneficial to fawn survival.

Deer select habitat at different spatial scales (Brunjes et al. 2006) and may even select habitat on a scale larger than their home range (Kie et al. 2002). Our research shows different land cover compositions and configurations within home ranges of MD and WTD fawns influenced fawn survival. Because fawn survival is an important driver of ungulate population

dynamics, understanding the effect of fawn survival rates on population growth will help predict future population trends and is necessary for managing deer populations across the Great Plains (Carstensen et al. 2009, Shallow et al. 2015).

Management Implications

Management for MD fawns, compared to WTD fawns, seems to be more essential due to low survival rates. To increase MD fawn survival, we suggest managing heterogeneous landscapes including a mosaic composed of irregular patches of native mixed prairie with interspersed CRP and agriculture lands. Maintaining existing native rangeland, and increasing available herbaceous cover in grazed native mixed-grass prairie will be important for the persistence of mule deer in western Kansas. Regardless of land cover, we suggest maintaining vegetative structure during early summer to provide fawns with concealment cover from predators in addition to thermal cover and insulation.

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Table 3.1 Mean, minimum, maximum, and standard error of maternal condition covariates used in Cox proportional hazards models to assess white-tailed deer (*Odocoileus virginianus*; WTD) and mule deer (*O. hemionus*; MD) fawn survival in western Kansas, USA 2018–2019.

Covariate[a]	Species	$\overline{x}$	Min.	Max.	Std. Error
Mass	MD	68.06	59.90	81.40	0.76
	WTD	66.22	55.80	76.20	0.77
Body Length	MD	159.11	142.00	169.50	0.97
	WTD	164.88	153.0	176.5	0.81
Foot Length	MD	47.72	45.00	52.00	0.20
	WTD	47.43	42.80	52.00	0.28
Chest Girth	MD	103.38	95.20	112.00	0.53
	WTD	102.82	95.00	109.50	0.51
Age	MD	4.53	2.50	10.50	0.25
	WTD	3.57	2.50	6.00	0.14
Body Condition	MD	7.47	2.00	10.00	0.24
	WTD	7.67	4.00	10.00	0.19
Loin Fat	MD	42.30	39.00	48.00	0.30
	WTD	42.59	33.00	50.00	0.59
Rump Fat	MD	5.58	2.00	11.00	0.29
	WTD	7.98	3.00	17.00	0.44

[a]Mass, mass at capture (kg); Body Length, length of doe from nose to base of tail (cm); Foot Length, length of rear leg from calcaneus to tip of the hoof (cm); Chest Girth, measured behind

front two legs (cm); Age, estimated age (yrs); Body Condition, scale (1-10) with 1-poor and 10-excellent; Loin Fat, measured with ultrasound (mm); Rump Fat, measured with ultrasound (mm).

Table 3.2 Mean, minimum, maximum, and standard error of continuous fawn intrinsic covariates used in Cox proportional hazards models to assess white-tailed deer (*Odocoileus virginianus*; WTD) and mule deer (*O. hemionus*; MD) fawn survival in western Kansas, USA 2018–2019. **Fawns ≥ 2 days old at capture (n = 7) were removed from intrinsic covariate summary statistics, but still used in Cox proportion hazards models.*

Covariate[a]	**Species**	$\overline{x}$	**Min.**	**Max.**	**Std. Error**
Birth Mass	MD	3.55	2.27	4.58	0.07
	WTD	3.28	1.38	4.62	0.10
Body Length	MD	63.98	55.00	68.50	0.45
	WTD	59.39	49.00	67.50	0.72
Foot Length	MD	25.82	23.00	29.00	0.19
	WTD	24.93	19.50	28.80	0.30
Hoof Growth	MD	2.66	1.42	5.21	0.11
	WTD	2.53	1.20	4.69	0.12

[a]Birth Mass, mass at birth (kg); Body Length, length of fawn from nose to base of tail (cm); Foot Length, length of rear leg from calcaneus to tip of the hoof (cm); Hoof Growth, measured from new growth line to basal hair (mm)

Table 3.3 Number (*n*) and percent (%) of cause-specific mortality events of fawns during 10-weeks observational period after birth in the summers of 2018-2019 in western Kansas distinguished between white-tailed deer (*Odocoileus virginianus*; WTD), mule deer (*O. hemionus*; MD) and study sites (North, South).

	Overall[a]		**MD**[b]		**WTD**[c]		**North**[d]		**South**[e]	
Mortality	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**
Unknown	23	0.38	14	0.40	9	0.36	11	0.39	12	0.38
Predation	22	0.37	12	0.34	10	0.40	11	0.39	11	0.34
Natural	13	0.22	8	0.23	5	0.20	5	0.18	8	0.25
Agriculture	2	0.03	1	0.03	1	0.04	1	0.04	1	0.03

[a] All white-tailed deer and mule deer fawn mortalities combined in both study sites

[b] Mule deer fawn mortalities in both study sites

[c] White-tailed deer fawn mortalities in both study sites

[d] White-tailed and mule deer fawn mortalities combined in the North study site

[e] White-tailed and mule deer fawn mortalities combined in the South study site

Table 3.4 Top-ranked univariate intrinsic models using Cox proportional hazards models for predicting white-tailed deer (*Odocoileus virginianus*) fawn survival in western Kansas between May and August 2018-2019.

Model[a]	**AICc**[b]	**ΔAIC_c**[c]	**w_i**[d]	**K**[e]	**LL**[f]
Fawn Mass	155.16	0.00	0.99	2	-75.43
Adult Body Condition	166.94	11.78	0	2	-81.33
Adult Loin	167.23	12.07	0	2	-81.47
Adult Chest	169.50	14.34	0	2	-82.61
Fawn Body	171.39	16.23	0	2	-83.55
Constant	172.46	17.30	0	1	-85.18

[a] Intrinsic variables related to fawn or adult does

[b] Akaike's Information Criterion corrected for small sample size

[c] Difference in Akaike's Information Criterion corrected for small sample size relative to minimum AIC_c

[d] Model weight

[e] Number of parameters

[f] Log likelihood

Table 3.5 Top-ranked univariate intrinsic models using Cox proportional hazards models for predicting mule deer (*Odocoileus hemionus*) fawn survival in western Kansas between May and August 2018-2019.

Model[a]	**AICc**[b]	**ΔAIC_c**[c]	**w_i**[d]	**K**[e]	**LL**[f]
Fawn Mass	209.00	0.00	1.00	2	-102.37
Adult Body Condition	225.51	16.51	0.00	2	-110.62
Site	238.37	29.37	0.00	2	-117.05
Constant	238.41	29.41	0.00	1	-118.16

[a] Intrinsic variables related to fawn or adult does

[b] Akaike's Information Criterion corrected for small sample size

[c] Difference in Akaike's Information Criterion corrected for small sample size relative to minimum AIC_c

[d] Model weight

[e] Number of parameters

[f] Log likelihood

Table 3.6 Cox proportional hazards models for predicting mule deer (*Odocoileus hemionus*) fawn survival using land cover composition within 95% biased random bridge home ranges, in western Kansas between May and August 2018-2019.

Model[a]	**AICc**[b]	**ΔAIC$_c$**[c]	w_i[d]	**K**[e]	**LL**[f]
Grassland^2	232.86	0.00	0.43	3	-113.19
CRP	233.94	1.08	0.25	2	-114.85
CRP^2	234.64	1.78	0.18	3	-114.07
Cropland^2	237.52	4.66	0.04	3	-115.51
Constant	238.40	5.54	0.03	1	-118.16

[a] Land composition variables; grasslands, croplands, Conservation Reserve Programs (CRP), woodlands, and urban areas

[b] Akaike's Information Criterion corrected for small sample size

[c] Difference in Akaike's Information Criterion corrected for small sample size relative to minimum AIC$_c$

[d] Model weight

[e] Number of parameters

[f] Log likelihood

Table 3.7 Cox proportional hazards models for predicting white-tailed deer (*Odocoileus virginianus*) fawn survival using land cover composition within 85% biased random bridge home ranges, in western Kansas between May and August 2018-2019.

Model[a]	**AICc**[b]	**ΔAIC$_c$**[c]	***w*** **$_i$**[d]	**K**[e]	**LL**[f]
Woodland	162.58	0.00	0.61	2	-79.15
Woodland^2	163.58	1.00	0.37	3	-78.51
Pasture	171.87	9.29	0.01	2	-83.80
Constant	172.46	9.88	0.00	1	-85.18

[a] Land composition variables

[b] Akaike's Information Criterion corrected for small sample size

[c] Difference in Akaike's Information Criterion corrected for small sample size relative to minimum AIC$_c$

[d] Model weight

[e] Number of parameters

[f] Log likelihood

Table 3.8 Cox proportional hazards models for predicting mule deer (*Odocoileus hemionus*) fawn survival using land cover configuration within 95% biased random bridge home ranges, in western Kansas between May and August 2018-2019.

Model[a]	**AICc**[b]	**ΔAIC$_c$**[c]	w_i[d]	**K**[e]	**LL**[f]
Landscape Shape Index	230.64	0.00	0.68	2	-113.20
Patch Richness	234.56	3.91	0.10	2	-115.16
Simpson's Diversity Index	235.11	4.46	0.07	2	-115.43
Interspersion Juxtaposition Index	235.97	5.33	0.05	2	-115.87
Largest Patch Index	236.14	5.50	0.04	2	-115.95
Edge Density	237.12	6.48	0.03	2	-116.44
Constant	238.40	7.76	0.01	1	-118.16

[a] Landscape metrics

[b] Akaike's Information Criterion corrected for small sample size

[c] Difference in Akaike's Information Criterion corrected for small sample size relative to minimum AIC$_c$.

[d] Model weight

[e] Number of parameters

[f] Log likelihood

Table 3.9 Cox proportional hazards models for predicting white-tailed deer (*Odocoileus virginianus*) fawn survival using land cover configuration within 85% biased random bridge home ranges, in western Kansas between May and August 2018-2019.

Model[a]	**AICc**[b]	**ΔAIC$_c$**[c]	w_i[d]	**K**[e]	**LL**[f]
Mean Perimeter-Area Ratio	170.22	0.00	0.44	2	-82.97
Constant	172.46	2.24	0.14	1	-85.18
Landscape Shape Index	173.62	3.40	0.08	2	-84.67
Perimeter-Area Fractal Dimension	173.82	3.60	0.07	2	-84.77
Edge Density	174.19	3.97	0.06	2	-84.96

[a] Landscape metrics

[b] Akaike's Information Criterion corrected for small sample size

[c] Difference in Akaike's Information Criterion corrected for small sample size relative to minimum AIC$_c$.

[d] Model weight

[e] Number of parameters

[f] Log likelihood

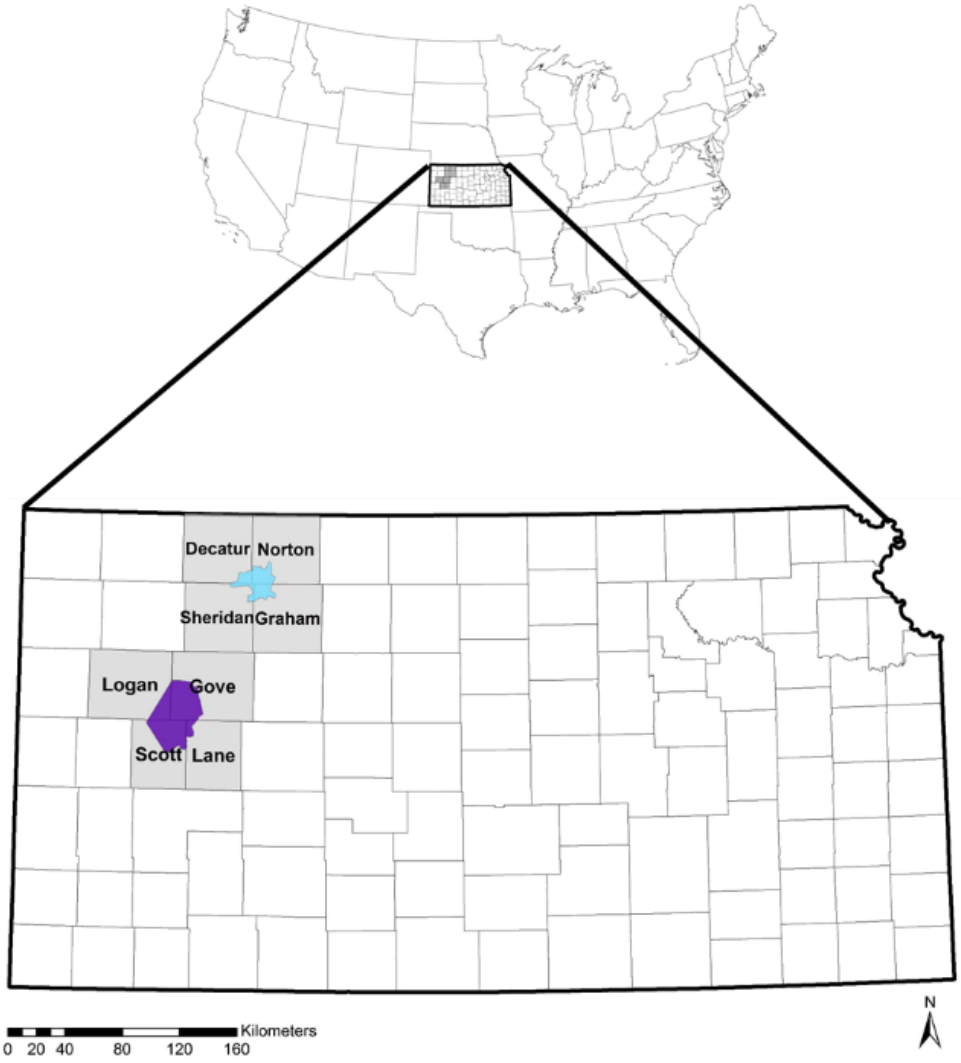

Figure 3.1 We captured fawns and assessed survival in mule deer (*Odocoileus hemionus*) fawns and white-tailed deer fawns (*O. virginianus*) in two study areas in western Kansas during the summer of 2018 and 2019. The North study site (blue) was located in Decatur, Norton, Sheridan, and Graham counties. The South study site (purple) encompassed Logan, Gove, Scott, and Lane counties.

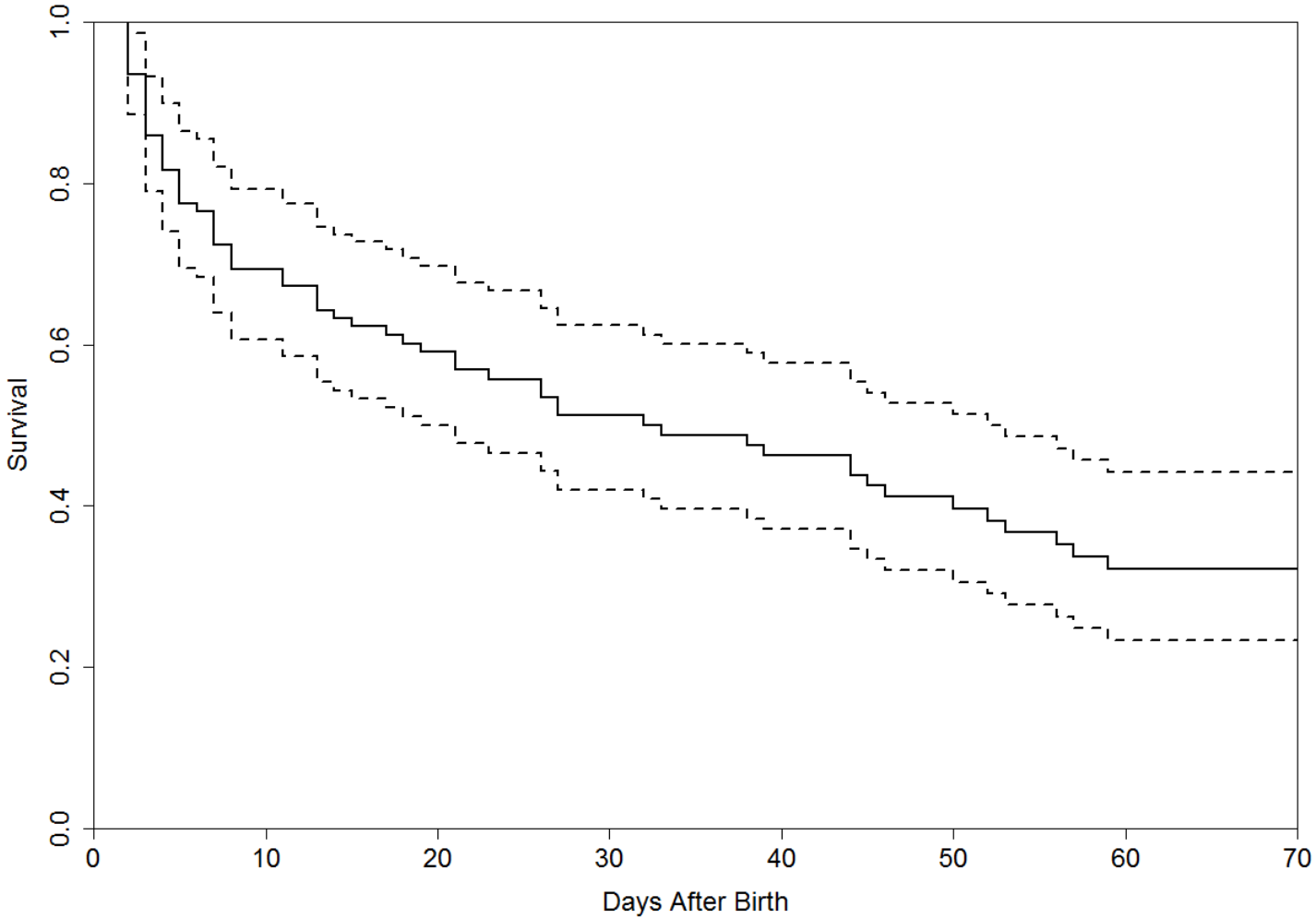

Figure 3.2 Known-fate Kaplan-Meier Curve estimating 10-week fawn survival for mule deer (*Odocoileus hemionus*) fawns and white-tailed deer fawns (*O. virginianus*) in western Kansas, USA 2018-2019. The dashed lines represent the 95% confidence interval and the solid line shows estimated survival rates.

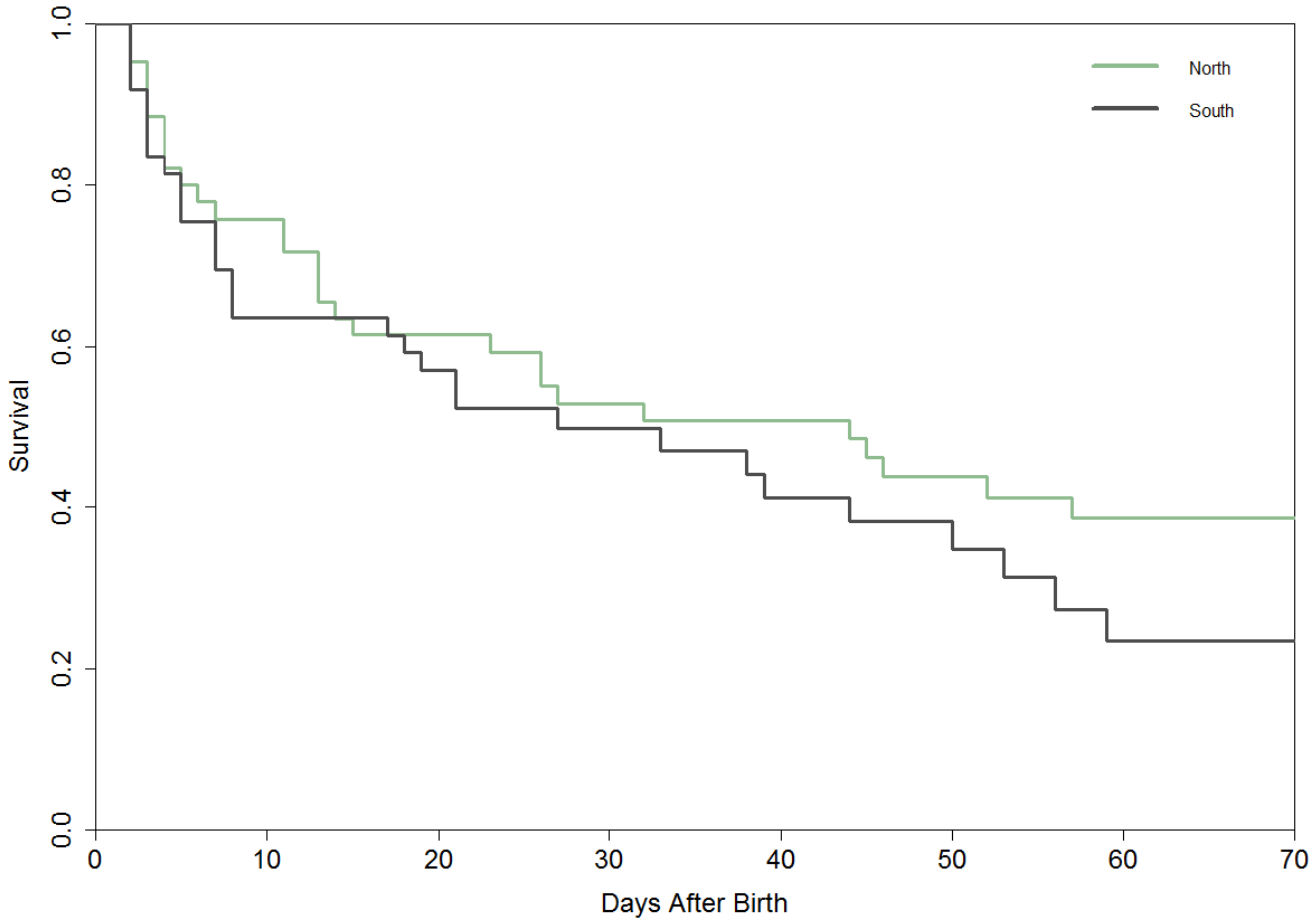

Figure 3.3 Known-fate Kaplan-Meier Curve separated by study site estimating 10-week fawn survival for mule deer (*Odocoileus hemionus*) fawns and white-tailed deer fawns (*O. virginianus*) combined in western Kansas for 2018-2019. The green line represents fawn survival in the North site and the gray line shows fawn survival in the South site.

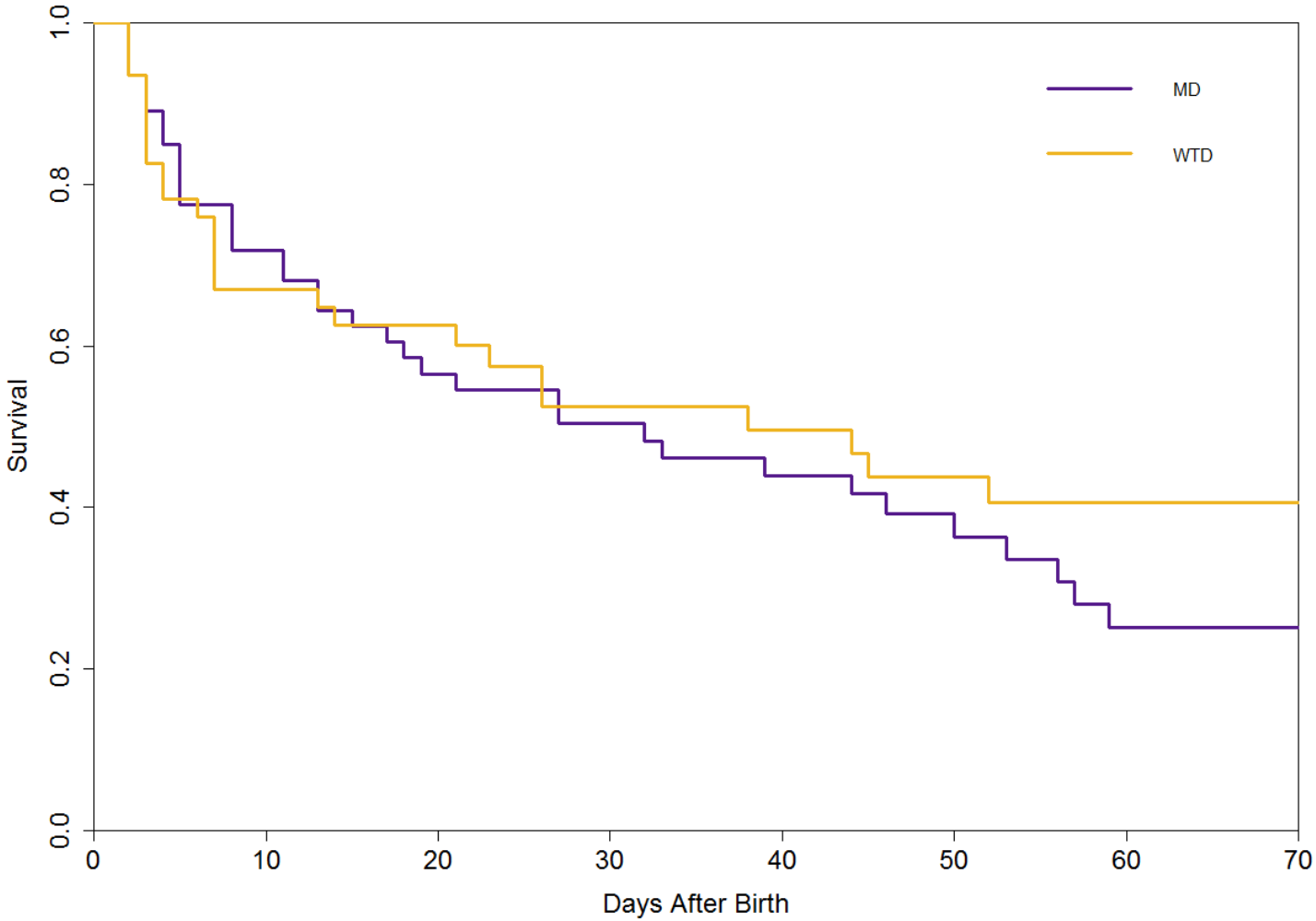

Figure 3.4 Known-fate Kaplan-Meier Curve estimating 10-week fawn survival for mule deer fawns (*Odocoileus hemionus*; MD) and white-tailed deer fawns (*O. virginianus*; WTD) in western Kansas, USA 2018 and 2019. The gold line represents WTD survival and the purple line shows MD survival.

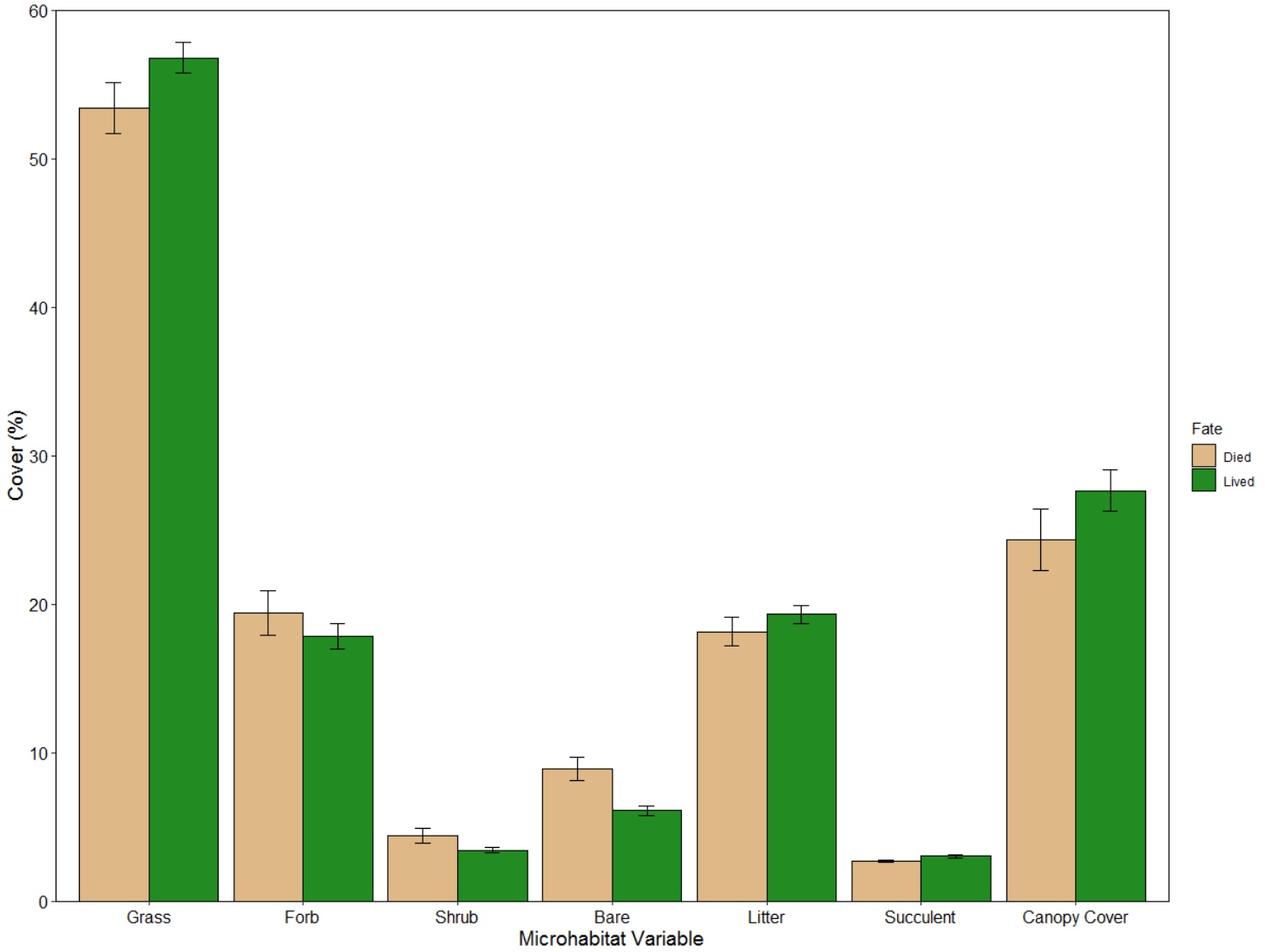

Figure 3.5 Comparison of vegetative composition in western Kansas at white-tailed deer (*Odocoileus virginianus*) fawn bed-sites that survived the 70-day observation period (green) and for fawns that died (tan) during the summer of 2018 and 2019.

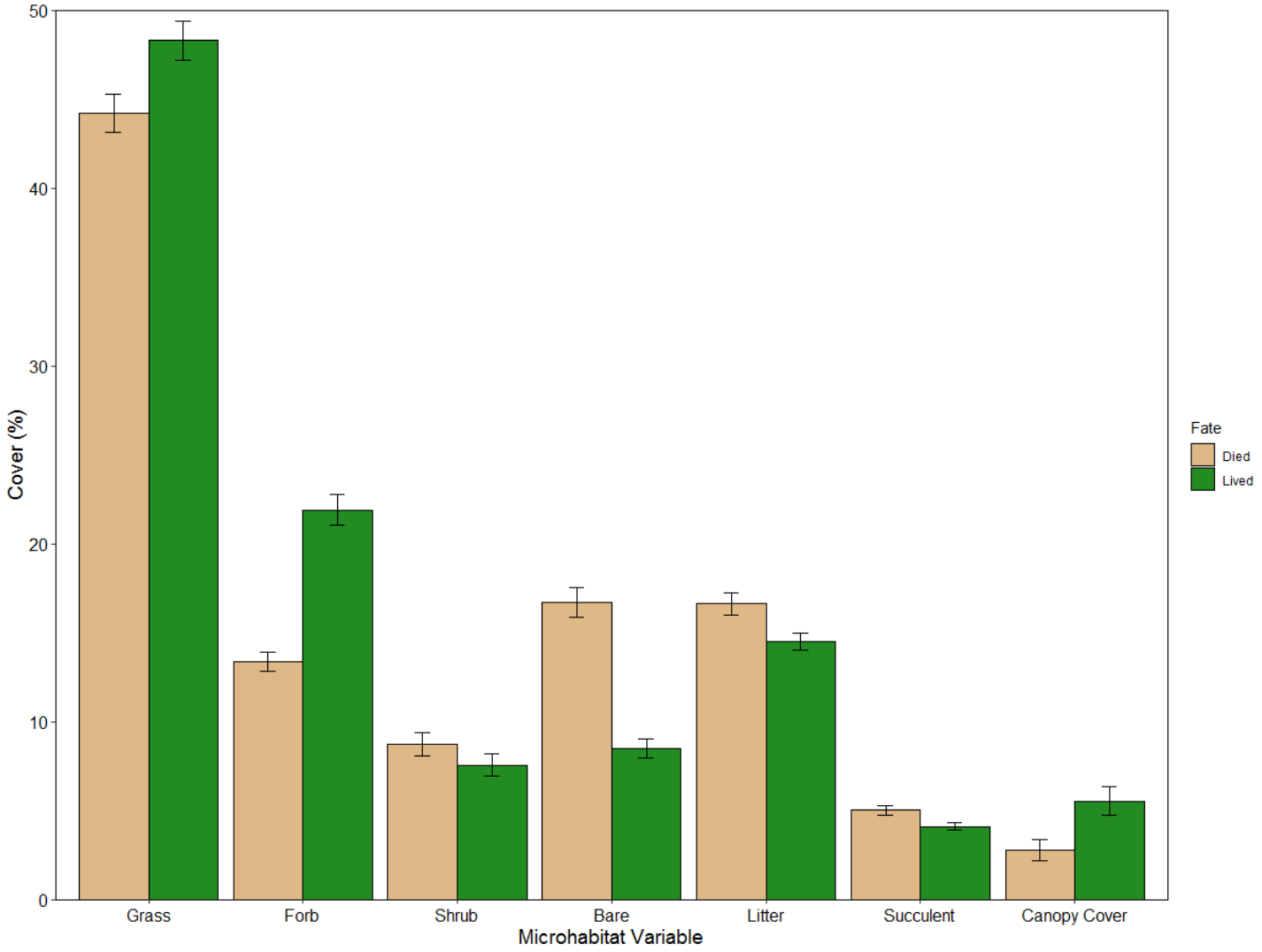

Figure 3.6 Comparison of vegetative composition in western Kansas at mule deer (*Odocoileus hemionus*; MD) fawn bed-sites that survived the 70-day observation period (green) and for fawns that died (tan) during the summer of 2018 and 2019.

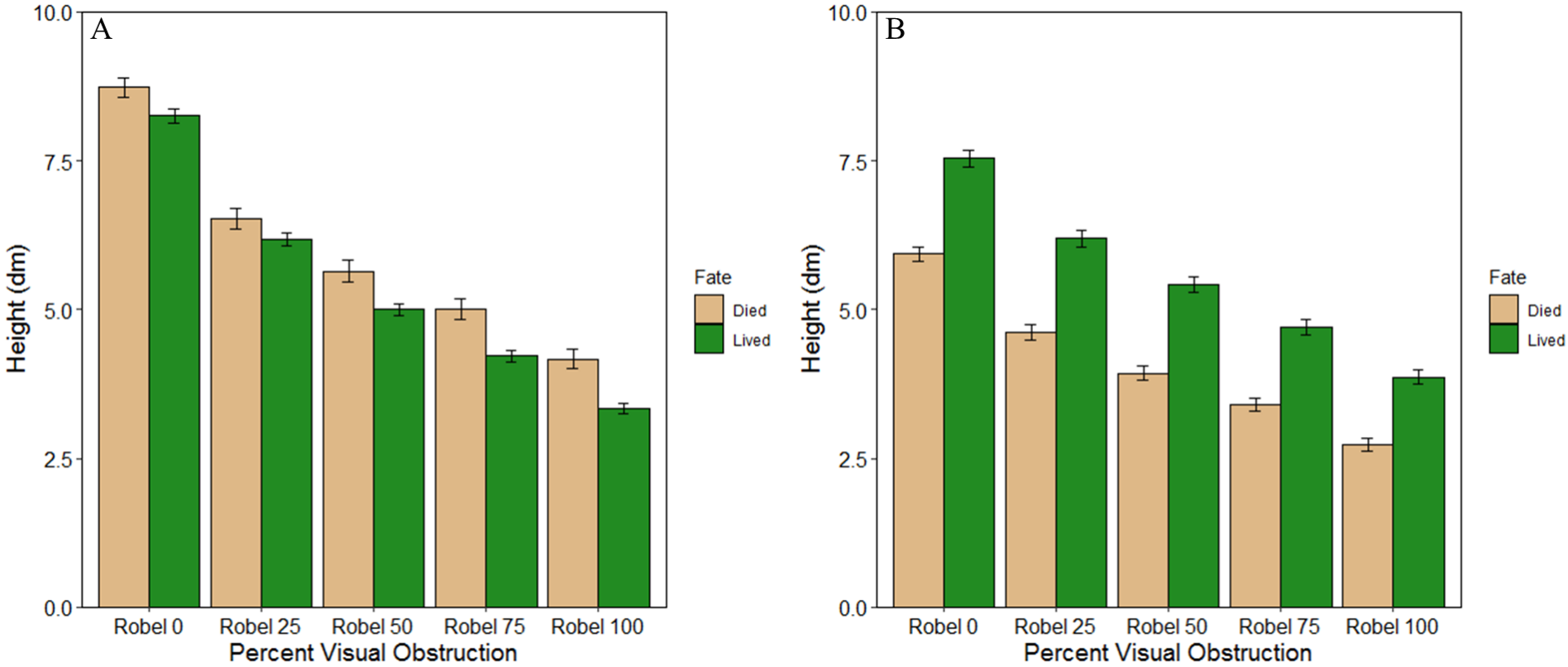

Figure 3.7 Comparison of visual obstruction in western Kansas at fawn bed-sites for white-tailed deer (*Odocoileus virginianus*; A) and mule deer (*O. hemionus*; B). Fawns are designated by those that survived the 70-day observation period (green) and fawns that died (tan) in the observation period during the summer of 2018 and 2019.

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Chapter 4 - Conclusion

Changes in land cover and vegetation have allowed white-tailed deer (*Odocoileus virginianus*; hereafter 'WTD') to colonize areas once dominated by mule deer (*O. hemionus*; Whittaker and Lindzey 2001, Brunjes et al. 2006; hereafter 'MD') and may influence fluctuating population trends within two sympatric deer species in the Midwest. White-tailed deer populations have expanded (Martinka 1968, Vander Hoek et al. 2002), while mule deer populations have contracted westward (Ballard et al. 2001, Shallow et al. 2015). While extinction is not an immediate concern for MD, populations will continue to shift westward and become limited if we do not implement management practices favoring MD. Managing MD populations is important, not only to maintain biological diversity within ungulate species, but also for economic reasons. Kansas alone sold 487,200 hunting licenses, tags, permits, and stamps in fiscal year 2019, which amounts to almost US$25 million dollars in sales (US Fish and Wildlife Service, Historical Hunting License Data 2019). These license sales help aid current management efforts, fund future wildlife research, and are important economically for rural communities.

Our overall objective was to determine if habitat selection, survival, and cause-specific mortality differed between WTD and MD fawns, and identify factors responsible for observed differences in population trends of MD and WTD in Kansas. Our major findings demonstrate 1) landscape composition and configuration within fawn home ranges influenced survival and had different effects on MD and WTD fawns; 2) vegetative structure was the best microhabitat predictor of fawn bed-sites; 3) mule deer and WTD showed similar landscape selection trends for bed-sites, although selection strengths and bed-site predictors differed by species; 4) adult morphometrics explained 70-day fawn survival in WTD, and fawn capture characteristics

explained 7-day fawn survival of both species; 5) microhabitat bed-site characteristics varied by fawn fate; and 6) white-tailed deer fawns had slightly higher survival rates compared to MD fawns, although this difference was not statistically different.

Top ranked survival models incorporating land cover configuration and composition differed between MD and WTD fawns (Chapter 3). Mule deer fawn survival was best explained by Landscape Shape Index (LSI) and increased with edge and disaggregation of land cover patches similar to other studies (Gulsby et al. 2017, Rohm et al. 2007). In the same model suite (Table 3.8), patch richness (PR) was the second ranked model and had a positive association with MD fawn survival. Percent composition of grasslands within a fawn's home range also increased MD fawn survival, but it exhibited a quadratic trend where grassland composition >42% negatively affected fawn survival. Collectively, LSI, PR, and grassland composition within MD fawn home ranges, all demonstrate the importance of land cover heterogeneity on MD fawn survival, and likely bolsters MD fawn survival due to increased proximity to multiple resources.

Woodland land cover within a fawn's home range explained survival in WTD fawns and fawn survival decreased as the woodland composition within a home range increased. Grovenburg et al. (2012) showed similar results in agriculture-dominated lands in South Dakota and suggested small linear patches of trees negatively affected WTD fawn survival by increasing predator search efficiency. It is likely that we saw similar results in Kansas as woodlands were comprised of narrow shelterbelts and small riparian patches, which likely benefited predator search efforts. Land cover configuration did not explain variation in WTD fawn survival, similar to fawns in Pennsylvania (Vreeland et al. 2004), and may relate to WTD being a more generalist species compared to MD.

CRP best predicted MD fawn bed-sites, and woodlands was the top predicting model for WTD fawn bed-sites. Odds of a bed-site were 2.85 times greater in CRP and 5.88 times greater in woodlands for MD fawns and WTD fawns respectively. White-tailed deer fawns may have fallen into an ecological trap as they selected bed-sites in woodlands, but woodlands had a negative effect on WTD fawn survival. We would actually expect bed-site selection pressures and survival relationships to hinder WTD fawn survival and benefit MD fawn survival; however, we did not observe that in western Kansas. We may not have seen a large effect related to the above selection-survival trends because we selected study sites where both species were abundant. Additionally, percentages of woodlands (~1.75%) and CRP (~7%) within the study sites were relatively low and may be too scarce for all individuals to inhabit the ideal landscapes identified by our bed-site selection models. In our case, there may not be enough CRP or woodlands on the landscape to reinforce observed land cover composition trends related to fawn survival. This suggests that a doe's home range, and the resulting land cover composition and configuration within a fawn's home range, may be more influential to fawn survival than selection of land-cover at the point scale. Although macrohabitat bed-site selection differed between species, it is likely fawns selected CRP and woodlands for dense vegetation providing visual concealment at the microhabitat scale.

We discovered differences in bed-site selection between MD and WTD fawns at the microhabitat scale (Chapter 2). Both species selected for heterogeneity at fawn bed-sites and herbaceous cover (measured as visual obstruction) was the driving force behind microhabitat bed-site selection. Herbaceous cover is commonly greater at fawn bed-sites (Hyde et al. 1987, Moorter et al. 2009, Grovenburg et al. 2010) and is influential to fawn survival by providing thermal cover (Moorter et al. 2009) and concealment cover from predators (Grovenburg et al.

2011). Although herbaceous cover was important to both species, we found MD fawns selected for denser cover compared to WTD fawns. We related the difference in vegetative structure density to individual movement behavior within the two species where MD movements favor agility and WTD movements are capable of greater speeds (Lingle and Pellis 2002).

Adult intrinsic variables best described 70-day WTD fawn survival while fawn intrinsic characteristics best explained 7-day fawn survival (Chapter 3). Intrinsic variables can influence fawn survival (Carstensen et al. 2009, Grovenburg et al 2012, Shuman et al. 2017), however, we removed the majority of intrinsic models from consideration because of high model uncertainty (Chapter 3). High model uncertainty indicates that there is not a strong relationship between fawn survival and most intrinsic variables that we measured, and is similar to results found for WTD fawns in South Carolina (Kilgo et al. 2012) and pronghorn (*Anitlocapra Americana*) fawns in South Dakota (Jacques et al. 2015). This suggests that other dissimilarities between the species (i.e., bed-site selection, land cover composition, habitat configuration) may have a more influential role on fawn survival in Kansas. Although landscape composition and configuration likely played a larger role in fawn survival in Kansas, we still suggest recording intrinsic characteristics as they represent cascading effects between habitat and fawn survival (Shallow et al. 2015).

White-tailed deer fawn survival was marginally greater than MD fawn survival in 2018 and 2019. Collectively, fawn survival was 1.6 times greater in WTD than MD (Chapter 3), but survival differences were not statistically significant. Survival was more similar between both species within the first 50 days of life, but MD fawns seemed to die more often than WTD fawns after 50 days. It is possible that WTD fawns are more capable of outrunning predators in open rangelands than similarly aged MD fawns because of differences in movement behavior (Lingle

and Pellis 2002). Although not reported in this manuscript, MD fawns had larger home ranges than WTD fawns in KS. This may indicate increased travel time to obtain resources in a lower quality habitat, which would leave fawns more susceptible to predation and malnutrition. Even though we did not see a statistical difference in survival between the two species, it is possible lower MD fawn survival rates could be biologically relevant. Lower overall fawn survival in MD decreases fawn recruitment, and may ultimately result in declining adult MD populations observed in Kansas.

We suggest continuing to monitor fawn survival in Kansas to increase sample sizes, and we propose a few ideas that could improve future research. The first is to use GPS collars instead of VHF collars on fawns. Although we made all our best efforts to limit disturbance to fawns (i.e., wore rubber boots, used alternative paths while GPS marking bed-sites, limited time near the fawn, and conducted bed-site vegetation a day later), it is possible our daily visual locations influenced fawn survival. Our project was unable to use GPS collars because of financial constraints and we needed to locate fawns daily to measure bed-site microhabitat data. For those technologically inclined, we would also suggest testing an unmanned aerial vehicle (UAV) with thermal imagery to help locate fawns at potential birth sites. The number of birth sites we searched and did not find fawns was relatively low (n =12, 10%), but UAVs might allow for quicker fawn acquisition, reduced stress experienced by deer, and possibly reduced time dedicated to fawn searching by project personnel.

The fawn research covered in this thesis is a limited portion of a much larger, multi-department deer ecology project at Kansas State University. Collectively, three graduate students studied MD and WTD survival, habitat selection, activity, and movement patterns of adult bucks, adult does, and fawns in western Kansas. The objective of the entire research project was to

identify key differences or similarities between the two species that could potentially explain underlying reasons for disparate population trends. We have shown different factors influencing fawn survival related to macrohabitat and microhabitat variables present at bed-sites for WTD and MD fawns. Observed differences between fawn survival and bed-site selection may influence population trends, but it is likely differences in the adult stages of life combined with our findings in the juvenile stage will offer the best explanation of divergent population trends in Kansas. In only considering the fawn aspect of this project, we recommend promoting CRP grasslands in a mosaic agriculture landscape to provide cover for fawns. We encourage grazing regimes that increase vegetative cover heterogeneity on the landscape and advocate using natural fallow rotations or planting cover crops, over chemical fallow fields, to increase available cover in croplands. Regardless of the land cover type, it is essential the habitat can provide thermal and visual cover allowing bedded fawns to remain hidden from predators during the early stages of life while still allowing fawns to remain mobile at older ages.

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